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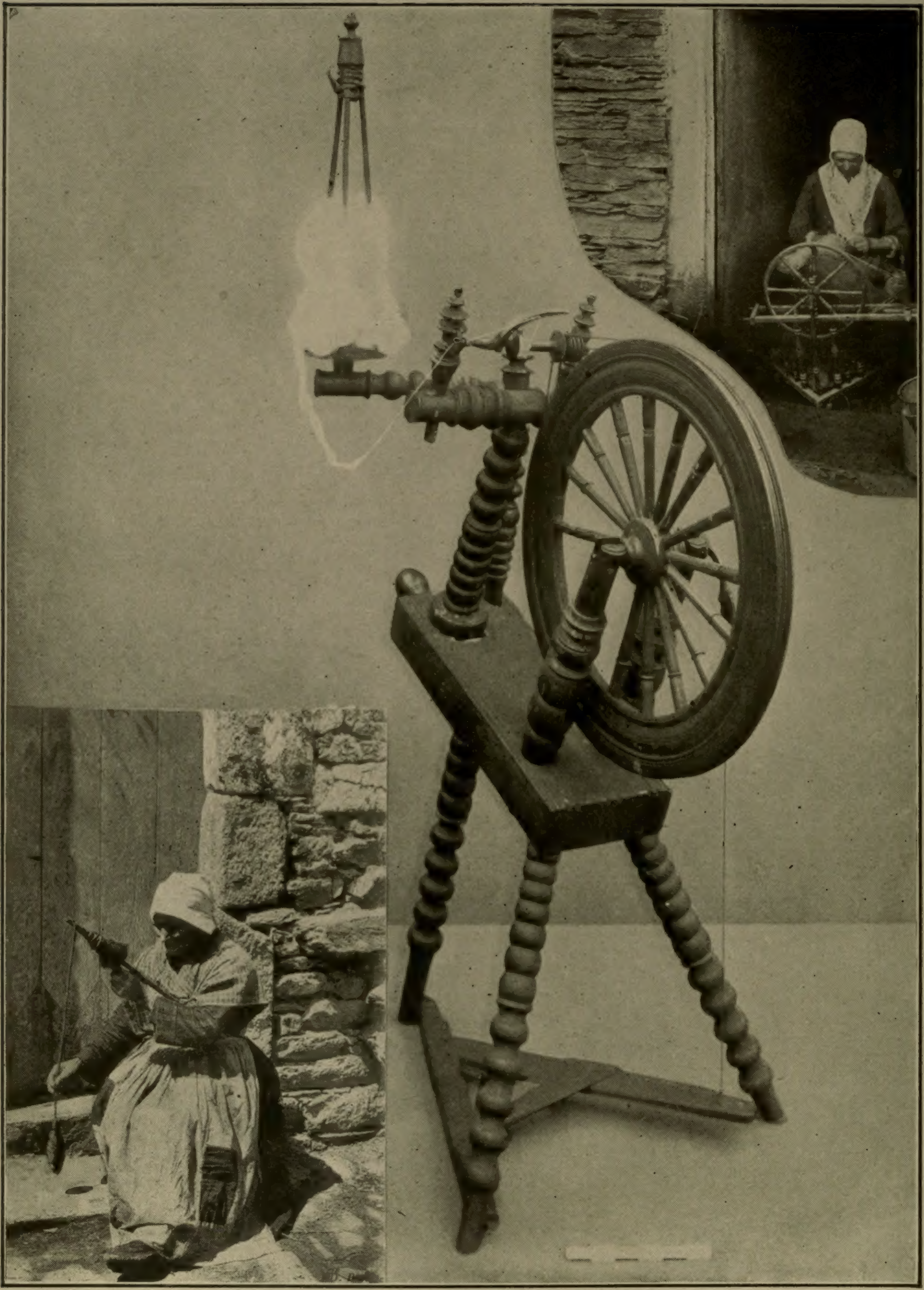

THE OLD WAY OF SPINNING.

The spinning wheel here represented was the property of Richard Arkwright, and is now preserved in the South Kensington Museum, London. It is of a type first introduced about 1530. The thread of cotton or wool passes through an eye in the axis of the spindle and is subsequently wound on the bobbin which rotates on the same axis but at a different rate of speed. The rotation of the spindle twists and strengthens the thread, and the difference in speed of revolution between the spindle and the bobbin results in winding the thread about the bobbin. The spinning wheel is still in use in many outlying districts of Europe, as suggested by the photograph of the Belgian peasant above presented. The even more primitive method of spinning with distaff and spindle, without the aid of a wheel —the spindle being rotated by the fingers, as shown in the lower figure—is also still extensively practiced by the peasantry of various European countries.

History of science.

(EVERY-DAY SCIENCE)

BY

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ASSISTED BY

EDWARD H. WILLIAMS, M.D.

VOLUME IX

INGENUITY AND LUXURY

ILLUSTRATED

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INGENUITY AND LUXURY

INTRODUCTION

CIVILIZATION is a synonym for artificiality. Man is not naturally adapted to live in any climate but a tropical one, and when he wilfully invades the inhospitable temperate zone, he creates artificial needs that require artificial aids for their fulfilment. It is tolerably obvious how this applies to food supplies—how the tropics supplied fruit to our primitive ancestor free for the taking, and how in the north he was obliged to become a fisher, a hunter, a grazer, and an agriculturist—in short a perpetual toiler forced to fight incessantly for the necessities of life.

What is true of the food supply is even more tangibly true as regards man's fight with the elements. In tropical forests clothing is almost a superfluity, and even the crudest house is a luxury rather than a necessity. But for the inhabitants of temperate and arctic zones it becomes imperative to conserve the bodily heat by incasing the body in an artificial covering, and by supplying an artificial environment, which is best secured by the building of houses. The prime object of these artifices is to prevent too rapid giving-off of heat by the body, through which the integrity of the bodily machine would be threatened. Such is the end subserved by the coats of feathers and of fur with which man's *confrères* of the animal world are provided by Nature. Divested of this natural covering, man has no resource but to provide an artificial substitute, or to take up his permanent abode in the tropics.

The evolutionist assures us that the time was when man was provided with a natural, heat-conserving covering of hair; as also there was a time when our remote ancestor did not attempt to stray beyond the tropics. In this stage of his development man doubtless neither felt the need, nor conceived the idea, of artificial clothing. It was only, we may suppose, when the wandering impulse—based probably upon the over-populating of his old environment—led him gradually to seek new territories away from the Equator, that the new experience of changing seasons brought to the growing intelligence of our primitive ancestor the idea of artificial protection from the weather. That idea once grasped and put into execution, and combined with the kindred idea of producing warmth with an artificial fire, gave man the key that unlocked the hitherto closed doors of the North Temperate Zone. Provided with these ideas of conserving the heat of the bodily machine—though as yet far enough from understanding the real nature of his discovery—man entered upon the difficult but alluring pathway to the conquest of the world.

When one reflects on the perpetual fight for life that man is obliged thus to wage against the elements, it seems strange indeed that a rational being should voluntarily subject himself to such a conflict. Yet all experience goes to show that strength comes only through exertion; that it is the very opposition of the elements that has developed man's intelligence. To supply the artificial needs which an unnatural environment has forced upon him, man has taxed his ingenuity; and the result is—civilization.

In the present volume we are concerned primarily with man's struggle with the elements—with his attempts to protect himself from wind and weather, and to conserve the heat supplied him by the food he eats, and which is essential to his existence. We shall witness man's method of satisfying desires that have grown up in connection with the artificial life of a housed, clothed, comfort-loving resident of uncomfortable climates.

We shall have to do with the materials of houses and the methods of house-construction—from tent and cabin to the modern skyscraper.

We shall consider also the materials with which man provides himself with an artificial body-covering; the mechanical devices with which he makes wool and flax and cotton into cloth, and the varying plans he has followed in fitting this clothing about his person—in a word, the story of costumes.

In all phases of this story of man's struggle with the elements we shall be concerned with the practical rather than with the esthetic. The latter, to be sure, cannot be altogether ignored, so closely is the task of the artisan interwoven with that of the artist. But, in the main, it is the utilitarian world that confronts us. We have to do, for example, with domestic architecture as a practical means of satisfying man's necessities and desires, rather than with architecture as a fine art; and we shall be concerned with the useful rather than with the esthetic aspects of clothing. Yet we shall perhaps be surprised to note how closely the two aspects of the subject are linked, and how generally estheticism waits upon utility. Moreover, we shall have occasion before we close to cross the border-line of the realm of mere utility, and to make excursions into the domain of art and luxury, following here the example set by man himself at all stages of his career, whether as savage, as barbarian, or as civilian.

I

AN INDUSTRIAL REVOLUTION

IT is difficult to say what substance was first used by primitive man for spinning—whether wool, cotton, or flax fibers—since all of these were used prehistorically. But the extensive and universal use of cotton is of comparatively recent date, and many of the remarkable inventions of machinery for spinning and weaving were designed primarily for using cotton fibers. Fortunately most of such implements will spin and weave wool and hemp as well as cotton, using certain modifications that do not affect the general principle, and a description of the cotton spinning and weaving machines will suffice to give a general idea of all the rest.

Just when cotton fabrics were introduced into Europe cannot be definitely determined, but it was certainly several centuries before the Christian era. It is probable that such fabrics came first from India, where the cotton plant is indigenous. Herodotus, who wrote his history about the middle of the fifth century, B.C., refers to the cotton garments of the Indians; and we know that in Roman times cotton had become a standard article of importation from the East. This traffic with Europe disappeared largely in the Dark Ages, but was revived again on the reawakening of Western Europe.

Many of the cotton fabrics woven by the natives of India were marvels of delicacy, and are still unequalled by western weavers. Some of the India muslins were of such delicate texture that they "were scarcely perceptible if crumpled in the hand; and if spread upon the grass when dew was falling, soon became invisible," if we may believe the description of an Indian missionary.

These muslins were hand-made, and although western workmen have striven to equal them, they have never been able to approach them in delicacy. The explanation of this lies, perhaps, in the difference in the temperaments of Hindus and Europeans. The Hindus are remarkable for their acuteness of touch, and their hands are unusually flexible and delicate. This combination of qualities probably accounts for their superiority as fine weavers. But another element should not be overlooked in this connection; cotton-weaving had been practised in India for many centuries, or perhaps even millenniums, before Europeans began it; and successive generations of skilled workmen in any field are sure to become extremely expert in their work. This fact, quite as much as any physical or temperamental differences in the races, may account for the Hindu weaver's remarkable dexterity.

The increasing importations of cotton fabrics from India during the seventeenth century began to alarm Europe, particularly England, where they seemed to menace the wool-manufacturers. Parliament passed a bill in 1700 forbidding the importation of India goods; but as smuggling was easy, the traffic still continued, and another act for a similar purpose, but still more stringent, was passed within a year of the first. As this did not have the desired effect, Great Britain adopted the more effective expedient of plunging into cotton-manufacturing herself; and although by the end of the century India was sending more cotton than ever to the British Isles, it was no longer as manufactured fabrics, but as raw cotton itself, to be woven into English cloth by English workmen and machinery.

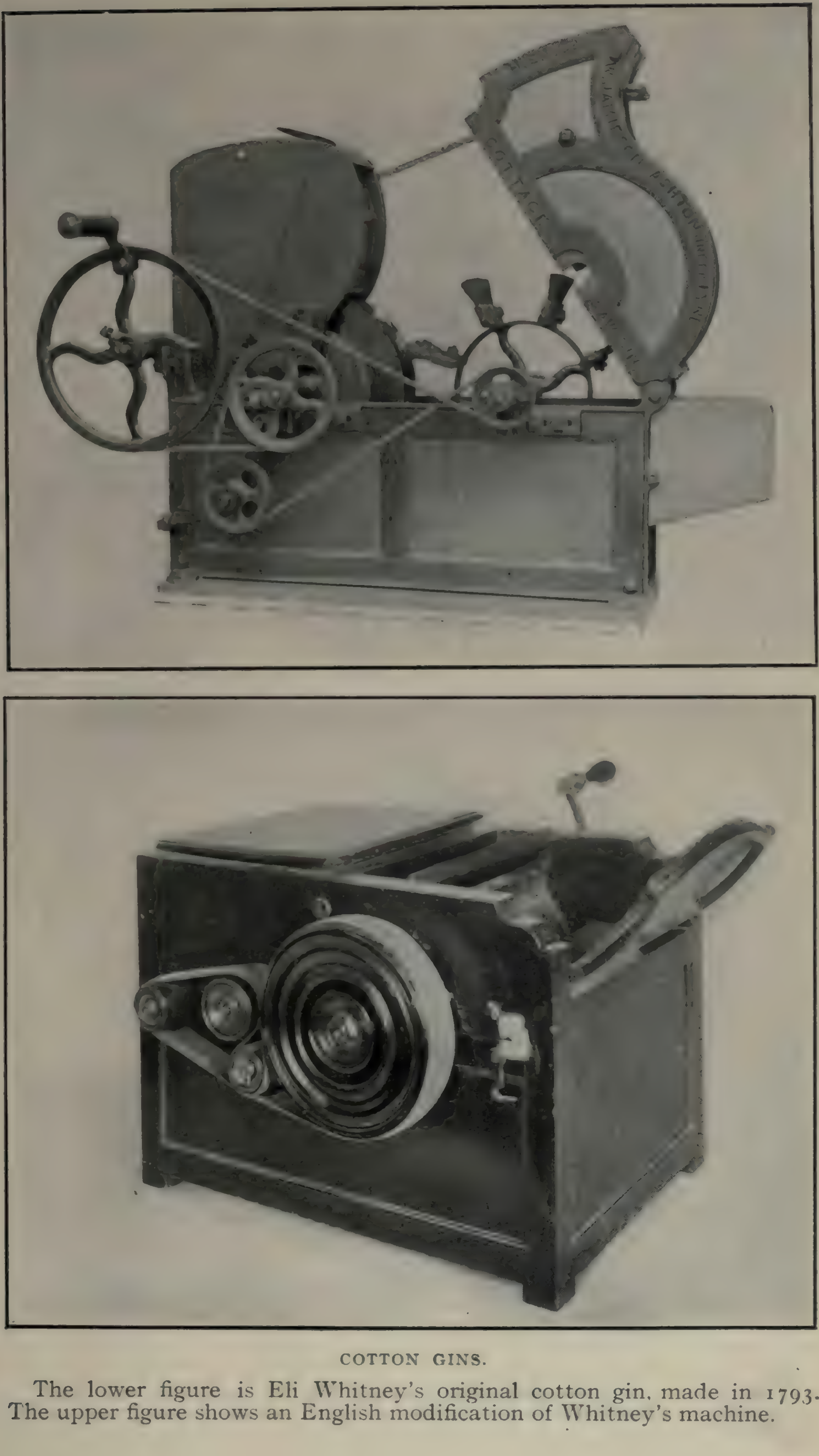
Before this time, however, America had become a source of cotton-supply and was rapidly growing in importance. Columbus had found cotton growing indigenously in most of the lands he discovered, and Cortez and Pizarro had made similar discoveries in Mexico and Peru. In fact, the cotton garments of the Aztecs were of such fine workmanship, that the conqueror of Mexico sent home specimens of these to his sovereign, Charles V, as a gift suitable for a monarch.

The cotton grown in the Western Hemisphere, however, was not equal in quality to the Indian product. It was not the same species of annual herbaceous plant now universally grown in the South, but seems to have been a variety grown on shrubs or small trees. No attempt was ever made to cultivate these native plants, but seed of the Indian plant was sent over from England, and probably cultivated by the American colonists in Virginia about 1620. The first official record of cotton being cultivated in America, however, is given in a report of the colony of Virginia in 1621, where it is mentioned among the other products. The climate of the South must early have appealed to the settlers as peculiarly adapted to cotton-raising, since the semi-tropical temperature, and relatively small amount of rainfall provided ideal conditions. Cotton-planters, therefore, began settling all through the southern districts, and by the time of the Revolutionary War cotton had become one of the staple American exports.

Until the latter part of the nineteenth century, and, in fact, until the close of the Civil War, India more than held her own in the matter of cotton production. Since that time, however, cotton-raising in the South has advanced with such rapid strides that at present over sixty per cent. of all the cotton in the world is grown south of the Ohio River, and north of the Rio Grande. Over seven million people are occupied in handling this crop, which is valued at about $500,000,000 annually; and something like seventy per cent. of the output is exported.

ELI WHITNEY AND THE COTTON-GIN

For many centuries the most tedious and difficult part of the cotton harvest was the separation of the seeds from the fibers, an operation called "ginning." The seeds stick to the cotton-fibers interwoven about them so tenaciously that by the old method of hand-ginning only a few pounds of cotton-fiber could be separated in a day by the workman. This was the great drawback to the use of cotton-fabrics, as a substance so difficult to harvest was proportionately



COTTON GINS.

The lower figure is Eli Whitney's original cotton gin, made in 1793. The upper figure shows an English modification of Whitney's machine.

expensive. But in 1793 the American, Eli Whitney, invented his cotton-gin, an implement which in its revolutionary effects has been little inferior to gunpowder itself.

Whitney was born at Westborough, Massachusetts, December 6, 1765. As a boy he had shown great mechanical ingenuity, having inherited a taste for machinery from his father, who was quite a skilful mechanic in a small way. Even as a boy of twelve years, young Whitney made many ingenious contrivances, among others a violin of fairly good shape and tone, and was recognized throughout his neighborhood as a boy possessed of unusual mechanical ingenuity.

The story is told that while still a small boy he became possessed with the very common child's desire to take his father's watch to pieces. Feigning illness at church-time one Sunday, therefore, Eli stayed at home, the rest of the family going to their place of worship some little distance from the house. No sooner had the family departed than Eli's illness vanished, and securing the watch left behind by his father he proceeded to take it to pieces. This part of the task was an easy one for any average boy; but Eli, after removing all the works, performed the more difficult one of putting them together again in proper order, leaving the watch running as before.

During the Revolutionary War young Whitney was quite successful in manufacturing nails by an ingenious process of his own; and afterward he engaged in the manufacture of hat-pins and walking-sticks. In 1789 he entered Yale College, and during his course of studies there frequently astonished his tutors by his ingenuity in repairing the scientific apparatus used in the laboratories, and in making various kinds of apparatuses of his own. Aside from this his college course was much the same as that of other students of corresponding age, although he became known as a vigorous and tireless worker.

His good fortune began with an acquaintance with the family of Gen. Nathanael Greene, of Georgia. Having been offered a tutorship in a Georgia family in the neighborhood of the Greene plantation, Whitney journeyed south to take the position, only to find upon his arrival that the place had been filled. Under these circumstances he was glad to accept the hospitality of Mrs. Greene, taking up his residence for the time being at her home. Here he soon had an opportunity of exhibiting his ingenuity. His hostess complaining one day that her tambour (a circular frame on which embroidery is worked) was unsatisfactory, and frequently tore her embroidery, Whitney offered to make her another, and soon produced a tambour far superior to any ever seen in the vicinity before. This, and some other ingenious devices, soon gave the young Yankee a reputation for ingenuity among the planters, and as a cotton-gin was the most needed implement in the region, he was urged by his hostess and her friends to attempt the invention of such a machine.

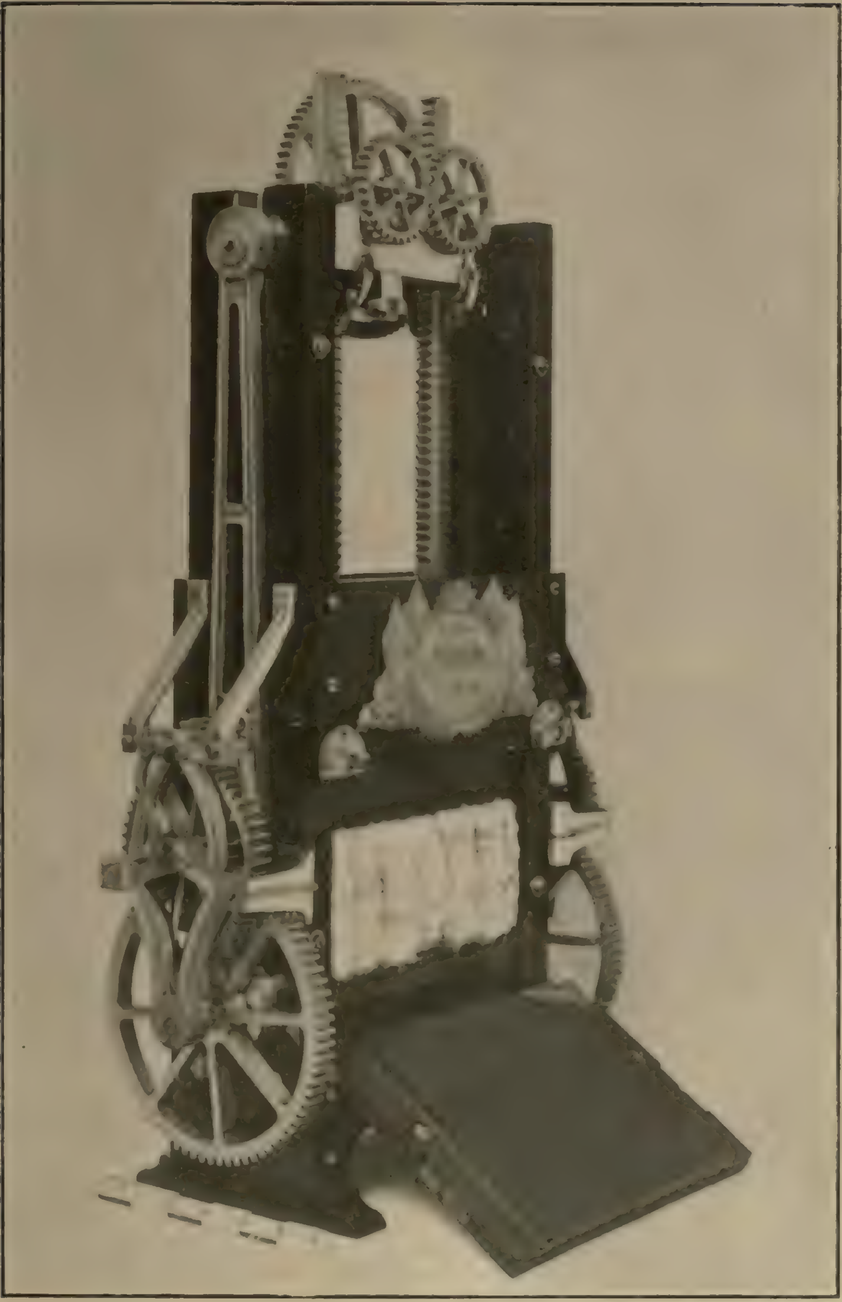
At that time, Whitney had never seen a boll of cotton, and knew nothing whatever of the process of ginning. He approached his subject, therefore, with the ignorance, but also the enthusiasm, of the novice. As an initial step he made a trip to the wharves at Savannah, and there succeeded in securing enough raw cotton for experimental purposes. A room in the Greene mansion was turned over to him for a workshop, and he set about his task. A few months later the doors of his den were thrown open, disclosing his wonderful creation, the "saw gin."

This remarkable machine consisted of a series of circular saws set close together on an axle, arranged so that they played between narrow slots in a comblike piece of metal. As the cotton was fed to these saws, the fibers were seized and drawn down through the slots, which were too small to allow the passage of the clinging seeds. A series of revolving brushes on the opposite side removed the cotton fibers, delivering them as fleecy cotton-down free from seeds, while the seeds rolled away into a receptacle made to receive them. By this machine, the work of a single man was increased at least a hundredfold, a day's work being no longer represented by the pound, but by the hundredweight.

As the news of this successful invention spread among the planters, Whitney soon experienced the treatment that seems to have been peculiarly the fate of almost every early inventor connected with the spinning- and weaving-industries. The inventors of the spinning-jenny, flying-shuttle loom, and mule, had their machines broken or destroyed; Whitney's gin was stolen. The differences in the motives of these similar acts of vandalism are in striking contrast. Whitney's gin was stolen by planters for use in hastening their work; Hargrave's and Kay's spinning- and weaving-machines were destroyed by mobs of workmen because they worked too fast.

Nevertheless, Whitney succeeded in bringing his specifications before the proper authorities and secured his patents. Later he returned to New Haven, Connecticut, and opened a factory for manufacturing his machines. Congress finally voted him $50,000; but as he became involved in litigation over his patent for several years, he realized, in the end, little or no financial gain for his great service to mankind. This is the more deplorable as his title as sole inventor seems to stand undisputed, and as his gin has proved such a boon to civilization—"more important in the history of the United States than all of its wars and treaties," as an English admirer of Whitney said a century later. How completely the inventor had solved the problem from the very first is attested by the fact that the modern gins used on American plantations are still of the Whitney type, very slightly modified.

When the cotton comes from the gin it is taken immediately to the presses and pressed into bales weighing about five hundred pounds. From these it is passed on to the "compressor," where it is still further reduced in bulk by enormous pressure ranging from one-thousand to fifteen hundred pounds to the square inch, the thickness of the bale being reduced to about four feet, six or seven inches. It is then secured with half a dozen iron hoops, and is ready for shipment to the mills.



COTTON BALING-PRESS

This form of press for compressing ginned cotton into bales is so arranged that the bales can be securely bound while under pressure.

In recent years the Americans have introduced a new system of baling, the cotton being pressed into flat layers, and rolled into cylindrical bales instead of the time-honored angular form. Such bales are made about four feet long and two feet in diameter, and weigh in the neighborhood of four hundred pounds each. It is claimed for this form of bales that they are more easily handled, can be packed more closely, and are both fireproof and waterproof.

COTTON AT THE MILL

There are various kinds and qualities of raw cotton, dependent upon the length and nature of the individual fibers themselves. Some cottons, such as the Sea Island, are composed of long, delicate fibers, while others have short, coarse fibers and are much less valuable. The gap between the very best and the poorest kinds of cotton is so great that no attempt is made to strike a general uniform average in such cottons by mixing; but in the intermediate varieties this mixing process is practised universally, and is the first process to which the raw cotton is submitted at the mills.

The quality of each bale of cotton as it comes to the factory is determined by microscopical examination of a certain number of fibers which are taken from different parts of the bale. This is particularly necessary where bales come from the smaller farmers, in which the products of several different pieces of land may be represented in each bale.

The older method of mixing was to place successive layers of cotton from each of the bales in a pile, and then pull and mix them by hand. In recent years, however, machines known as "bale-breakers" or "cotton-pullers" have been invented to take the place of the more primitive method. These machines consist of several pairs of rollers, either fluted or carrying coarse spikes, which pull and mix the cotton. Thorough mixing is obtained by feeding the cotton from the several bales into the machine at the same time.

After leaving the mixer the cotton goes at once to the "opener," a machine which loosens the fibers and shakes and blows out any foreign matter in the form of grains of sand, seeds, leaves, etc., that are sure to have crept in during the process of gathering and shipping. The cotton is spread in a uniform layer on the feeding-table of the machine, from which it is taken by the feed-rollers and carried within reach of a cylinder fitted with projecting teeth, and known as the "beater." This cylinder revolves at a rate of a thousand or more revolutions a minute, and quickly loosens the fibers as they come into contact with the teeth; while at the same time a strong draught of air is blown through the cotton, still further loosening any particles of foreign matter that may cling to it. It may pass over several of these beating-cylinders, and blowing-machines, before it finally emerges from the machine in the form of a "lap"—a flat layer or sheet of cotton—and is wound upon a cylinder.

From these cylinders it is fed to the "scutcher," which is really a modified form of opener. In this machine the cleaning-process, by means of beaters and currents of air, is continued and repeated, if necessary, until every trace of foreign matter is removed, and the cotton-fibers are thoroughly loosened.

From the scutcher the cotton goes to the carding-machine, perhaps the most important of all those through which it has passed since leaving the gin. In the carder the last remaining particles of impurities are removed, defective fibers are plucked out, and the tangled fibers from the lap are combed into parallel order.

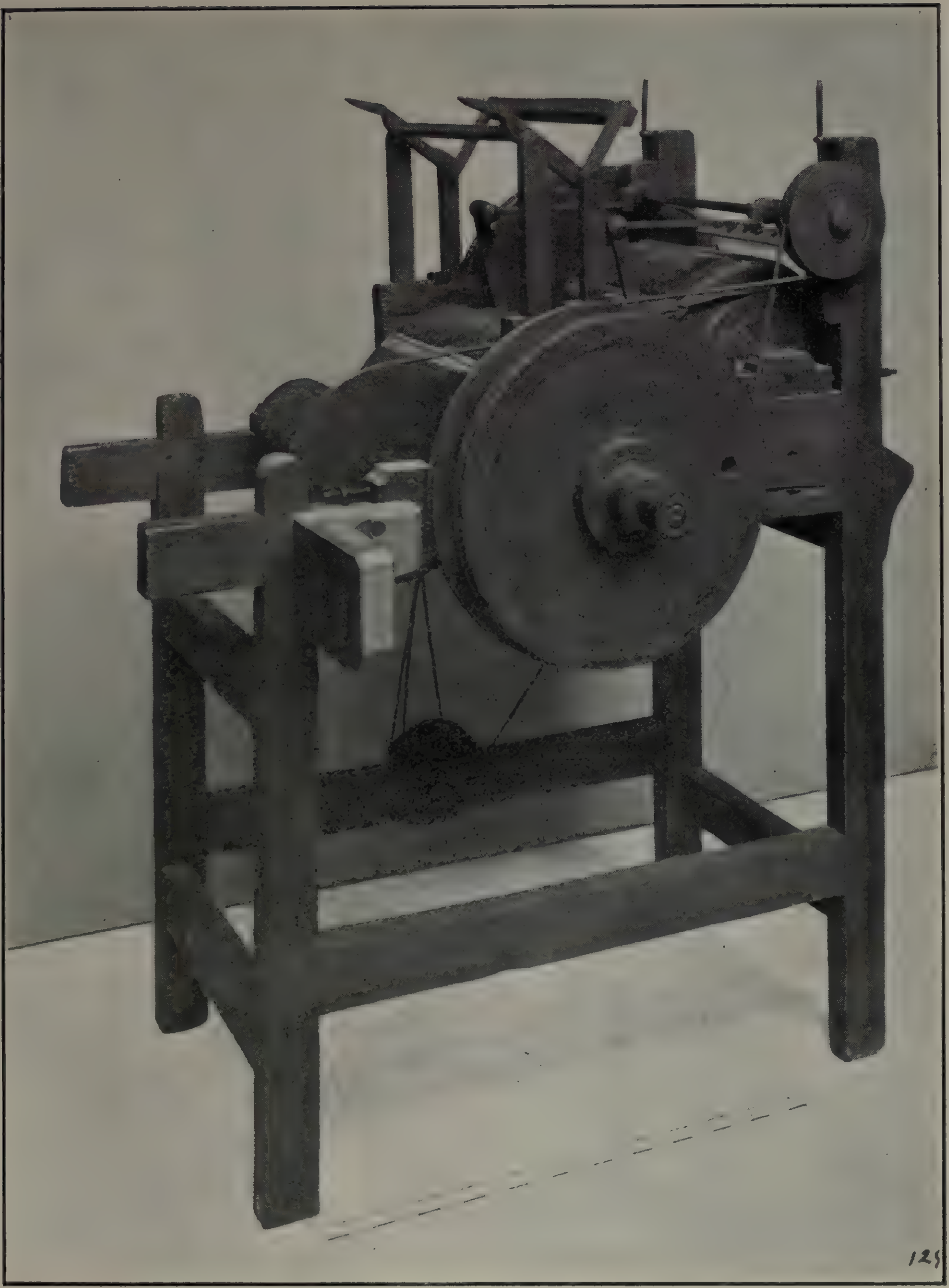
In the raw cotton, as it comes fron the scutcher, there are many imperfectly developed fibers which are found about the seeds in the boll, and which are mixed with the perfect fibers in the ginning. There are also imperfect fibers from other causes in the cotton, which, if allowed to pass the card and be spun or woven, would make defective threads and consequently poor material. These are all removed in the carding-machine, along with bits of leaves and seeds that may have escaped the other machines. But although this removal is a necessary function of the carding-machine, its use, primarily, is to comb the fibers into parallel rows—the beginning of the actual process of spinning.

Carding by hand, as performed before the invention of the rotary carding-machine, was done by means of ordinary hand-cards—pieces of boards covered with leather, from which bristled thousands of short wires, like needles protruding from a cushion. These needles grasp and separate and make parallel the fibers, just as a wire hair-brush, which is simply a modified hand-card, smooths the hair.

The first improvement over this simple method of carding was made by James Hargreaves, the inventor of the spinning-jenny, of whom we shall have occasion to speak more fully in a moment. He arranged sets of cards by suspending them so that the amount of work performed by a workman was doubled. A little later, in 1762, he was employed by the statesman, Robert Peel, to construct a carding-machine, which he finally completed in the form of a cylinder bristling with wire teeth. This machine worked in a most satisfactory manner, and is the true parent and prototype of the elaborate carding-engines in use at the present time. Various modifications and improvements were made in this machine from time to time, but the original principle of the carding-cylinder has been retained in all subsequent machines.

The layer of cotton enters the carding-engine as a lap of cotton with fibers lying indiscriminately in all directions, passes over successive cylinders designed for certain definite purposes, becomes a thin cloudlike film of cotton fibers lying approximately parallel and free from all foreign particles, and finally emerges through a conelike opening in the form of a white strand, or "sliver" as it is called, composed of untwisted cotton-fibers. From this funnel-shaped tube the sliver is automatically coiled in a can placed to receive it, and is then ready to be sent to the drawing-frames.

As the slivers from the carding-machines reach the drawing-frames the fibers forming them, while approx-



THE ORIGINAL CARDING MACHINE.

This is Arkwright's original carding machine, the predecessor of all carding machines of the present day. It is preserved in the South Kensington Museum, London. This machine was made about the year 1775. It is very similar to the cylindrical carding machine invented and constructed by Daniel Bourne of Leominster in 1748. The object of the machine is to remove from the cotton any fragments of leaves, sticks, etc., and also to straighten out the fibres by a combing action. This is accomplished by small wire teeth fixed in large leather strips upon three cylinders. The cylinders are arranged horizontally with their axes parallel and are rotated at different speeds.

imately parallel, as just stated, are not sufficiently so, nor distributed with the necessary uniformity, to be used immediately for making yarn. It is the function of the drawing-frame, therefore, to perfect the arrangement of the fibers and to combine a certain number of slivers, usually six, into another "rove" of cotton, which has the general appearance of the original sliver. The perfecting of the parallel arrangement of the fibers is done by the ingenious arrangement of pairs of rollers, each successive pair acting a little more rapidly than the preceding, and thus "pulling into line," as it were, the successive fibers. This type of machine was first devised by Sir Richard Arkwright, whose invention will be described more fully presently.

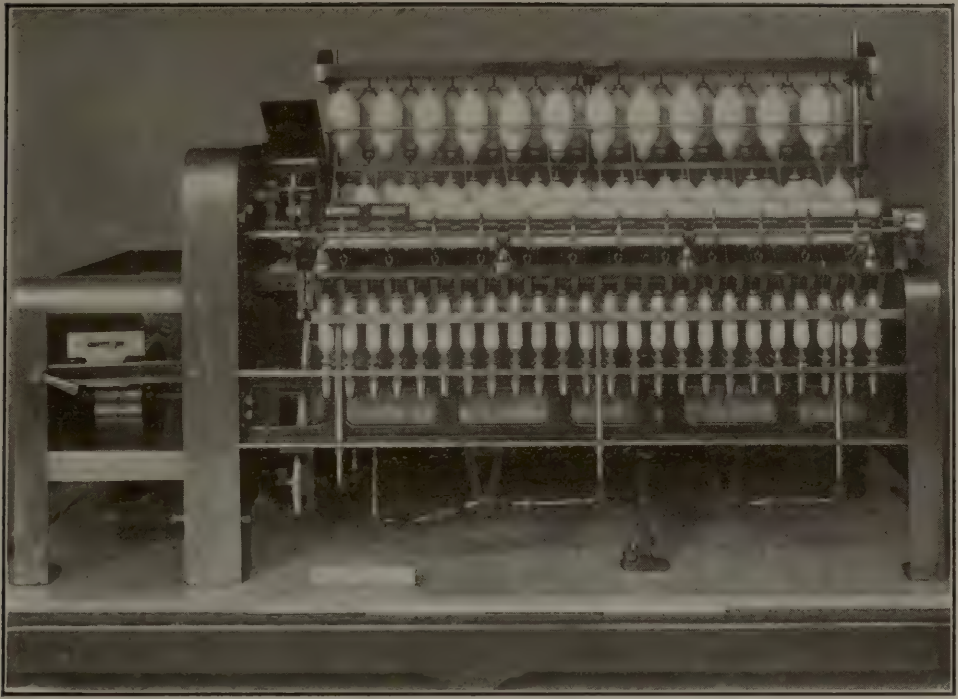
Up to this point the machines engaged in handling the cotton have been employed in preparing it for the final twisting into strands and threads, rather than in actually preparing such threads. But on emerging from the drawing-frames, it goes to a series of three more frames, which still further draw out the cotton, and wind it upon bobbins. In the first of these machines, or slubbing-frame proper, the end of the sliver is seized by rollers, twisted and wound upon bobbins which are then transferred to the intermediate frame. This is a machine built on practically the same general principles as the slubbing-frame, in which the two strands of the bobbins from the slubber are wound into one. The last of these series of machines is one known as the roving-frame, in which the cotton yarn is still further twisted and reduced in size.

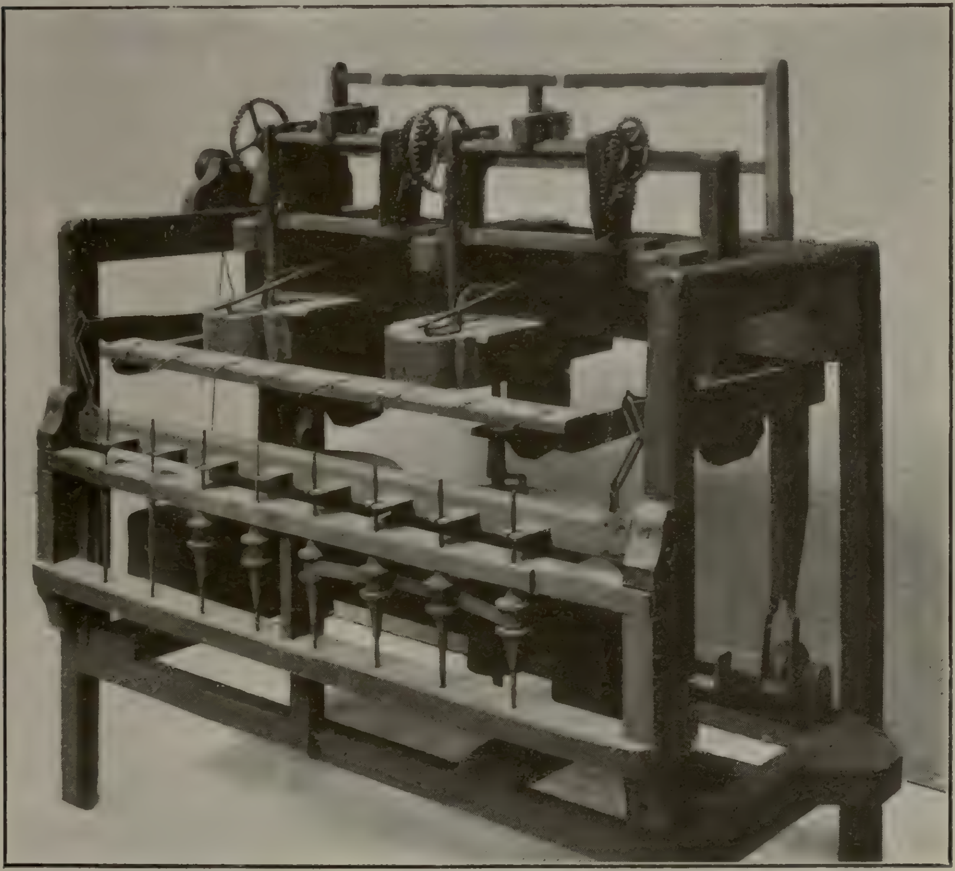
This, in brief, is the process of modern spinning. It is subject to many modifications, however, and the machinery used is so complicated that it is difficult to understand from any description, even if fully illustrated. Probably an account of how the various machines were developed will convey a better idea than a detailed description of the machines themselves in their present complicated form. Before we turn to this, however, we must examine briefly the processes by which that other chief textile-material, wool, is prepared for the spinner.

PREPARATION OF WOOL FOR SPINNING

Though certain breeds of sheep produce far superior wool to others, not all the wool of any sheep is of first-grade quality. In fact, the best fleece of any sheep comes from a narrow strip along either flank of the animal, extending from just in front of the shoulder to a point in front of the hip. From this finest quality of wool, coming from the side of the animal, there is a gradual falling off in quality toward the other parts of the body, until the product about the head and legs becomes so coarse and stiff that it is more like hair than wool.

An important part of the wool-manufacturing industry is the sorting or stapling, separating the wool into lots of uniform quality. This work is done by skilled workmen who have learned by long experience to determine almost instinctively the exact quality of each bunch of wool handled. The stapler usually





ARKWRIGHT'S IMPROVED SPINNING MACHINE AND A MODERN MACHINE.

The lower figure shows an improved Arkwright machine made about 1775. Its principle of action is precisely that of his earlier machine, but it has an arrangement for guiding the yarn over the bobbins evenly, and it contains more spindles. The upper figure shows a modern ring-spinning frame. This is a shortened example having only 48 spindles. In a complete frame, as used in a cotton factory, there would be about 400 spindles.

works at a frame covered with wire-netting which allows the dirt and dust to fall through, picking out the separate qualities and throwing them into the proper receptacles. He also removes all foreign substances such as straws or burrs, so that each particle of wool as it comes from his table is practically free from coarser fragments.

When thus sorted, the wool is ready for scouring. This is a very important process, and the quality of the resulting manufactured product, such as the taking of the dye colors evenly, is largely dependent upon the careful and complete manner of doing it. The water used should be pure and soft, and the soap of good quality, or the resulting product will be rough and harsh to the touch, and take the dyes unevenly. The older method was to place the wool in hot soap-suds in a large vat, keeping it stirred constantly with long poles until the grease was dissolved and the dirt thoroughly separated. It was then drained, washed with a stream of water, and dried. Many substances were used in the place of soap, but in recent years a specially prepared potash soap is used almost exclusively. The operation is now hastened by mechanical means, and a much smaller quantity of soap used than formerly, by first steeping the wool in pure water, or by blowing steam through it. This not only removes mechanical impurities, but softens the fibers and hastens the scouring process. The wool is then passed on to machines that agitate it gently so as not to ball it, and it is finally squeezed between rollers and sent to the dyeing-machines.

This is also a delicate process, which must be done gradually and uniformly if the best results are to be obtained. Sometimes this dyeing is done by centrifugal machines, but other kinds of machines are used, most of which keep the wool spread and turned evenly in a chamber heated to the proper temperature. But even after the most careful dyeing the wool is still matted, and must be opened and brought to a loose and free condition. This is done by passing it through a series of rapidly revolving drums set with spikes and so arranged that, as the various drums revolve in opposite directions, the spikes of one just clearing those of its neighbor, the wool is teased and becomes disentangled, light, and fluffy.

The natural wool contains quite a high percentage of a peculiar oil, called the "yolk" or "suint," which is removed by the action of the soap-suds in the scouring process. This leaves the wool harsh and wiry, and some oily substance must be added to make it properly soft and elastic, and also to make the fibers more adhesive so that a more level and finer yarn can be spun. The application of the oil must be absolutely uniform, and the quantity just sufficient to soften the fibers without excess or waste. To do this the wool is placed in machines that carry it in thin layers to a spraying aparatus, which sprays it uniformly with oleine, olive oil, or lard oil.

One more operation is necessary before the wool is ready for spinning or weaving, this being the blending either of different qualities of wool, or with cotton or other fibers. This is done in much the same manner as in blending cotton, separate layers being passed over each other, and then thoroughly teased until a uniform blend is obtained.

From this point onward the process of manufacture is practically the same for wool as for cotton. The various spinning-machines and looms are practically the same, modified in details for certain purposes, and need not be considered separately. The story of the development of these machines centers about the cotton industry; but what is said of the manufacture of this textile applies equally, with certain modifications as to details, to the sister textile as well. We may note here, however, that wool is habitually worked into two quite different types of yarn, known respectively as "worsted" and "woolen" yarn. In worsted yarns the fibers are long and lie nearly parallel with one another, so giving the material a smooth surface. The fibers of woolen yarn, on the other hand, lie in all directions, with many loose ends projecting so giving a rough surface. But cloth woven from these rough fibers, when felted or milled, presents a smooth and even surface, concealing the individual threads, owing to the interlacing of the individual fibers during the milling process. The difference in texture between worsteds and woolens as presented in the finished goods is familiar to every one.

HARGREAVES AND THE SPINNING-JENNY

For over a century England has been the center of cotton- and wool-manufacture of the world; the revolutionary inventions of her sons have given her this position. Yet the treatment accorded these inventors by fellow Englishmen makes anything but creditable history. Official England, to be sure, stands in a better light in these matters; and the English Government, as is usual in such cases, did well by the gifted inventors. But little can be said of the English workingmen who mobbed John Kay for inventing the flying-shuttle which revolutionized weaving; drove out of the country James Hargreaves because he had invented his spinning-jenny with which one man could perform the work of many, and destroyed the factories of Sir Richard Arkwright, the inventor of the spinning-frame. When we reflect that the inventions of Kay, Hargreaves, and Arkwright eventually gave England her exalted position in the manufacturing world, the action of the ignorant mobs of workmen, sometimes observed, but not interfered with, by officials, seems the more inexcusable.

In 1858, Mr. Cole, in a paper read before the British Association, attempted to show that the first inventor of a spinning-machine was one Lewis Paul, of Birmingham, who made such an invention in 1738. In this paper Mr. Cole brought some striking evidence in support of his belief that Paul's invention acted by means of rollers on something the same principle as Arkwright's spinning-frame, invented thirty years later.

There is no question, however, that the machine which came to be known as the spinning-jenny was the invention of James Hargreaves and of him alone; and this machine must be credited with being the first practical mechanical device for performing the same work as the ancient spinning-wheel. Hargreaves was an illiterate and humble weaver living at Standhill, near Blackburn, in England, and the story is told that he first conceived the idea of his spinning-machine by observing an overturned wheel and noticing that the spindles seemed to work as well in the vertical position as in the horizontal. Experimenting along the lines suggested by this idea, he finally constructed a machine consisting of a frame containing a number of vertical spindles and actuated by a wheel turned by hand, upon which he was able to spin about a dozen threads simultaneously in the same length of time, and with no greater effort than was required to spin a single thread by the old method. The first patent was taken out for this machine in 1770, Hargreaves constantly adding improvements to his device, until he was able to spin as many as thirty threads as easily as a single one.

Hargreaves describes his patent as covering "a method of making a wheel or engine of an entire new construction, and never before made use of, in order for spinning, drawing, and twisting cotton, and to be managed by one person only, and that the wheel or engine will spin, draw, and twist sixteen or more threads at one time, by a turn of motion of one hand, and a draw of the other." The following is his description of the process: "One person, with his or her right hand turns the wheel, and with the left hand takes hold of the clasps, and therewith draws out the cotton from the slubbing-box; and, being twisted by the turn of the wheel in the drawing out, then a piece of wood is lifted up by the toe, which lets down a presser-wire, so as to press the threads so drawn out and twisted, in order to wind or put the same regularly upon the bobbins which are placed on the spindles."

The description is not very intelligible to one who has not seen a model of the machine,—particularly as most persons nowadays are unfamiliar with the process of spinning which was an every-day practice in all ordinary households at the time when the spinning-jenny was invented. It will perhaps aid in understanding the process to explain that the entire method of reducing cotton to a spun thread consists in drawing out the fibers until they are practically parallel and then twisting them so that they cling tightly together. In primitive spinning the drawing process was accomplished by hand, and the final twist given by a revolving spindle. Hargreaves' invention did not change the principle but only made it possible for the operator to manipulate several or numerous threads at once. A revolutionary method of effecting the same ends was introduced by another inventor soon after the introduction of the spinning-jenny as we shall see in a moment. But first we must follow the fortunes of the spinning-jenny itself.

As soon as the wonderful possibilities of this new machine became known among the cotton-workers in the neighborhood, Hargreaves' shop was attacked, his spinning-jenny destroyed, and the inventor driven from his home. Fleeing to Nottingham Hargreaves again constructed his spinning-machines, the merits of which were finally appreciated, the inventor being recognized as a great benefactor to mankind.

But like most pioneer inventions in new fields, the spinning-jenny was defective in many ways. Only certain kinds of thread could be spun on it, and the cotton rove, or film of cotton fibers from which the yarn is spun, had to be carefully carded before it could be used. But even with the greatest care it was impossible to spin yarn or threads strong enough to act as warp, the thread as made by the spinning-jenny being only suitable for weft.

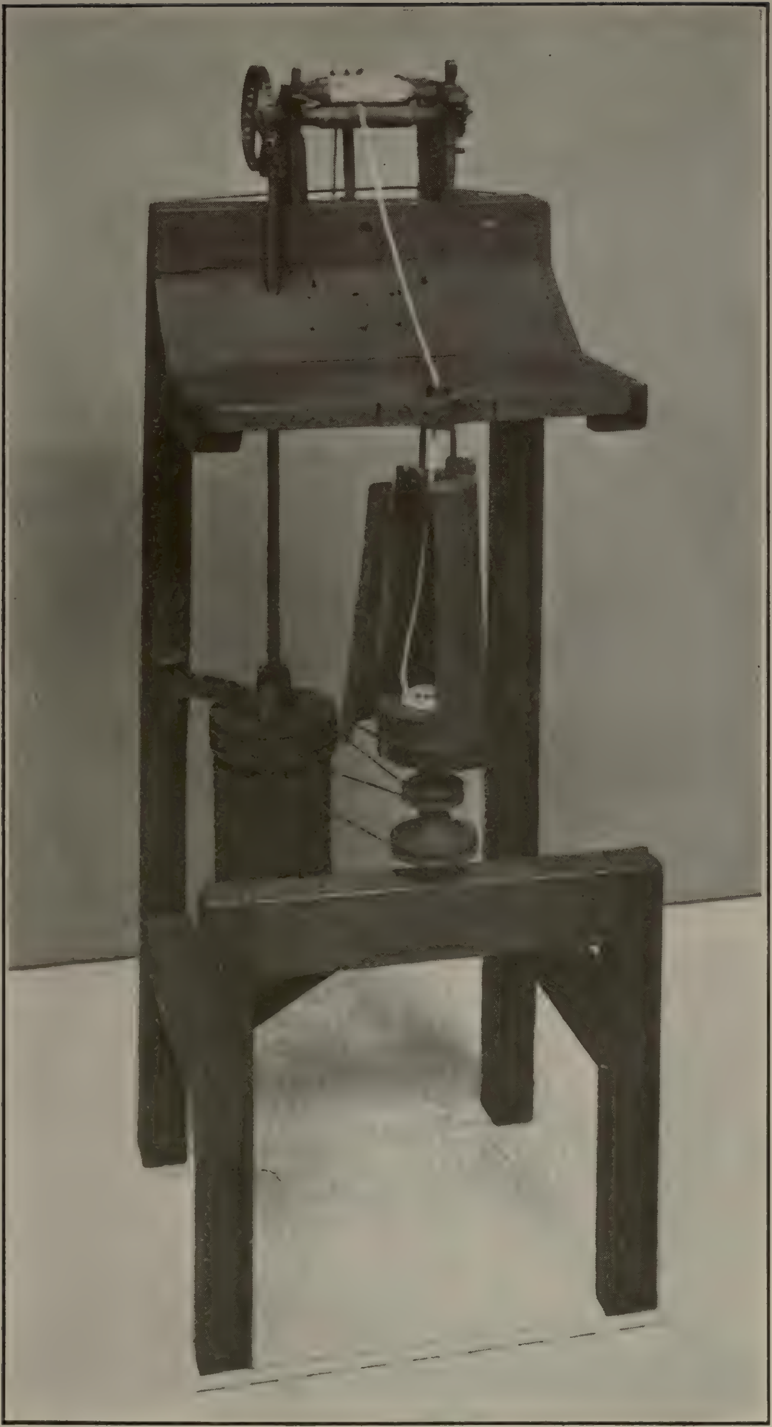
As most people are unfamiliar with the exact meaning of the terms "warp" and "weft," it should be explained that in weaving, a certain number of threads lying parallel and running longitudinally are first fastened into the weaving-frame. The threads are known as warp-threads. In the process of weaving other threads are passed alternately over and under these longitudinal threads, row after row, until the cloth is completed. These transverse threads are called the weft, and it is obvious that such threads need not necessarily be so strong as the warp-threads. It was only these weft threads and not the warp, that could be spun upon Hargreaves' spinning-jenny.

ARKWRIGHT INVENTS THE WATER-FRAME

The machine that finally solved the problem of making warp-thread was the creation of Richard Arkwright, barber, hair-dyer, and man of inventive genius, of Preston in Lancashire. Arkwright was born in 1732, the youngest in a family of thirteen children. Having little education and being extremely poor, he was apprenticed as a boy to a barber; later on becoming master of a shop of his own. Having a naturally inventive turn of mind he devoted much of his time to experimenting in various fields, finally succeeding in producing a chemical process for dyeing hair which produced him sufficient income to allow him to devote more of his time to various inventions which he had conceived and partially developed.

Living, as he did, in the cotton-manufacturing district, he was probably familiar with Hargreaves' spinning-jenny, and if so he was certainly aware of its defects. It is certain, at any rate, that his inventive efforts were along entirely different lines from those pursued by Hargreaves in his machine. In 1769 he took out his first patent for spinning by means of rollers, and soon after perfected a machine with which he was able to spin a great number of threads at any desired degree of thinness or hardness.

In this "spinning-frame," or "water-frame" as it was called, there were two pairs of rollers, set horizontally and parallel, like the rollers of a wringer. The lower roll of each pair was furrowed or fluted longitudinally, while the upper rollers were covered with leather to make them take hold of the cotton. If both these pairs of rollers are revolved at the same speed and a rove of cotton passed through them, it is obvious that aside from the compression given by the rollers, no change will be produced. If, however, the second pair of rollers is revolved more rapidly than



ARKWRIGHT'S ORIGINAL DRAWING FRAME.

This is Sir Richard Arkwright's first drawing frame and was made by him about 1780. It was commonly known as the "lantern" frame, owing to the fact that the sliver-can employed has an opening in the side closed by a door through which the sliver was removed, and so somewhat resembles a lantern. The process of drawing is accomplished by passing the wisp of cotton fibres through two pairs of rollers that nip it, the second pair revolving more quickly than the first. The distance between the two pairs of rollers is rather more than the length of the fibres, so that the drawing only slides the fibres upon one another without stretching or breaking.

the first, it is obvious that the rove of cotton will be stretched and pulled to any desired degree of tenuity according to the relative speed of the two sets of rollers. This was the principle upon which Arkwright's spinning-frame worked, and as the necessary twist was given the threads by an adaptation of the spindle and fly of the common flax-wheel, perfect threads could be manufactured very rapidly.

Here was a complete departure in principle from any method of spinning attempted heretofore, unless the doubtful claim of Lewis Paul be recognized, and its simplicity and practicality at once appealed to persons interested in cotton manufacture. The idea of utilizing rollers for spinning was said by Arkwright himself to have been suggested to him by seeing red-hot iron bars elongated by being passed between rollers.

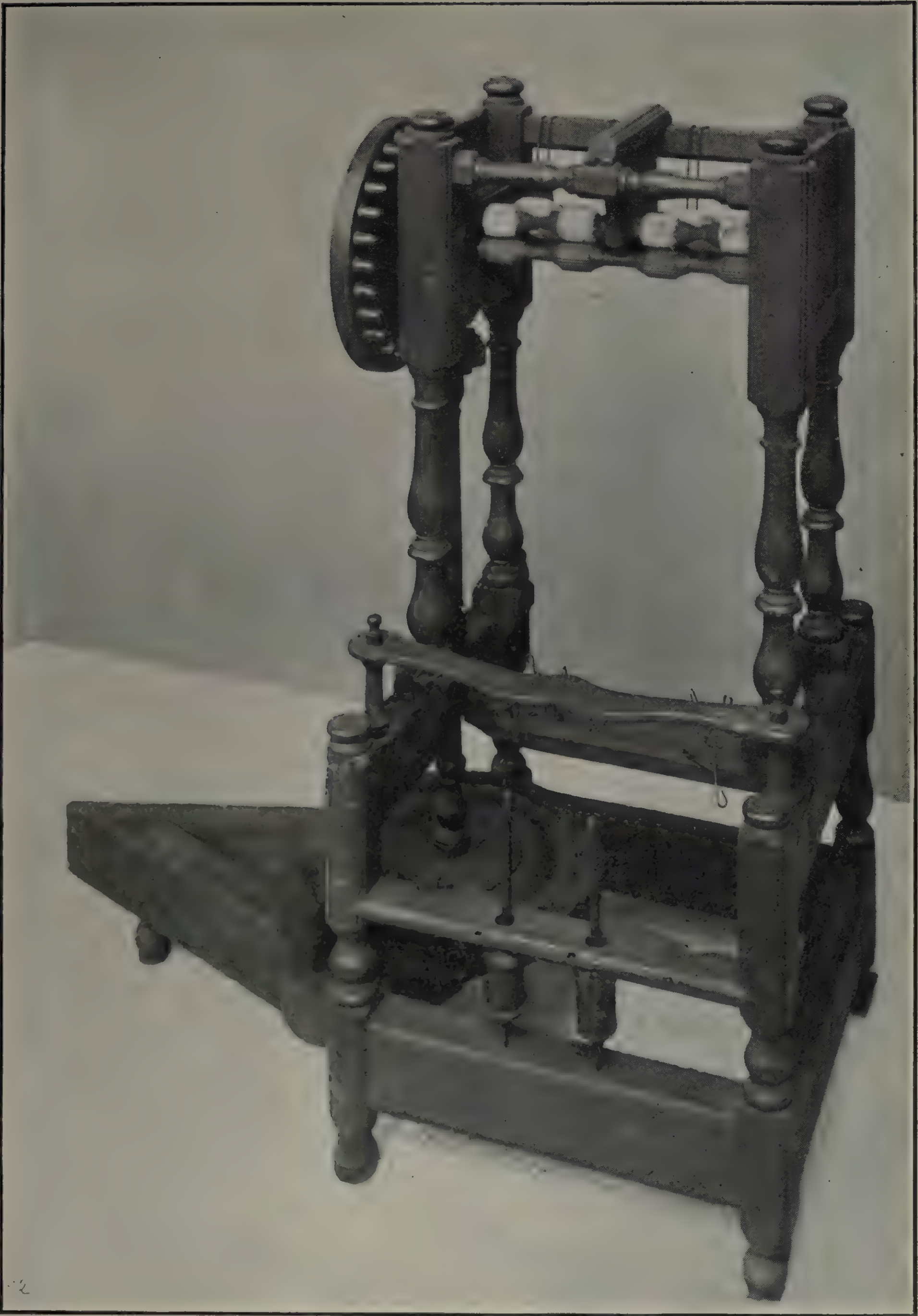
Profiting by Hargreaves' experience with the lawless mobs of Lancashire, Arkwright took his invention to Nottingham, where he attempted to interest some capitalists in establishing a factory. For some little time he was unsuccessful, but finally a Mr. Strutt, of Derby, becoming convinced of the possibilities of the spinning-frame, assisted the inventor in constructing his first mill at Nottingham, horse-power being used. While this experiment showed that the spinning-frame was capable of performing an extraordinary amount of work, the power for running the factory proved so expensive that in 1771 Arkwright constructed a new mill at Cromford, this mill being run by water-power, and for this reason his invention came to be known as the "water-frame." Later on its modified form was given its present name, "throstle."

Thus far Arkwright had escaped the lawless mobs of English workmen; but as his business ventures prospered he invaded the enemy's country, and built a mill at Birkacre in Lancashire, the home of machine-breaking mobs. He was soon treated to the same experiences as the earlier inventors, Kay and Hargreaves—his mill and machines were destroyed by a mob. What made the act the more disgraceful was the fact that a large body of police and military witnessed this wanton destruction of valuable property, and tacitly showed their approval by not attempting to check it. Unlike the two other unfortunate inventors, however, Arkwright's financial position was such that the loss of one mill had little effect upon his prosperity.

THE TRIBULATIONS OF AN INVENTOR

But meanwhile a formidable enemy was preparing to attack him. This was a body of men composed of the great cotton-manufacturers, who formed a "combine" for the purpose of wresting from him the rights to the patents of his spinning-frames. These manufacturers were not content to sit calmly by and see Arkwright prosper by producing better products for less money than they themselves could unless they paid him a royalty for the use of his machines.

Twelve years after taking out his first patent, therefore, Arkwright was called into court to defend his rights. The case was tried in the Court of King's



ARKWRIGHT'S ORIGINAL SPINNING MACHINE.

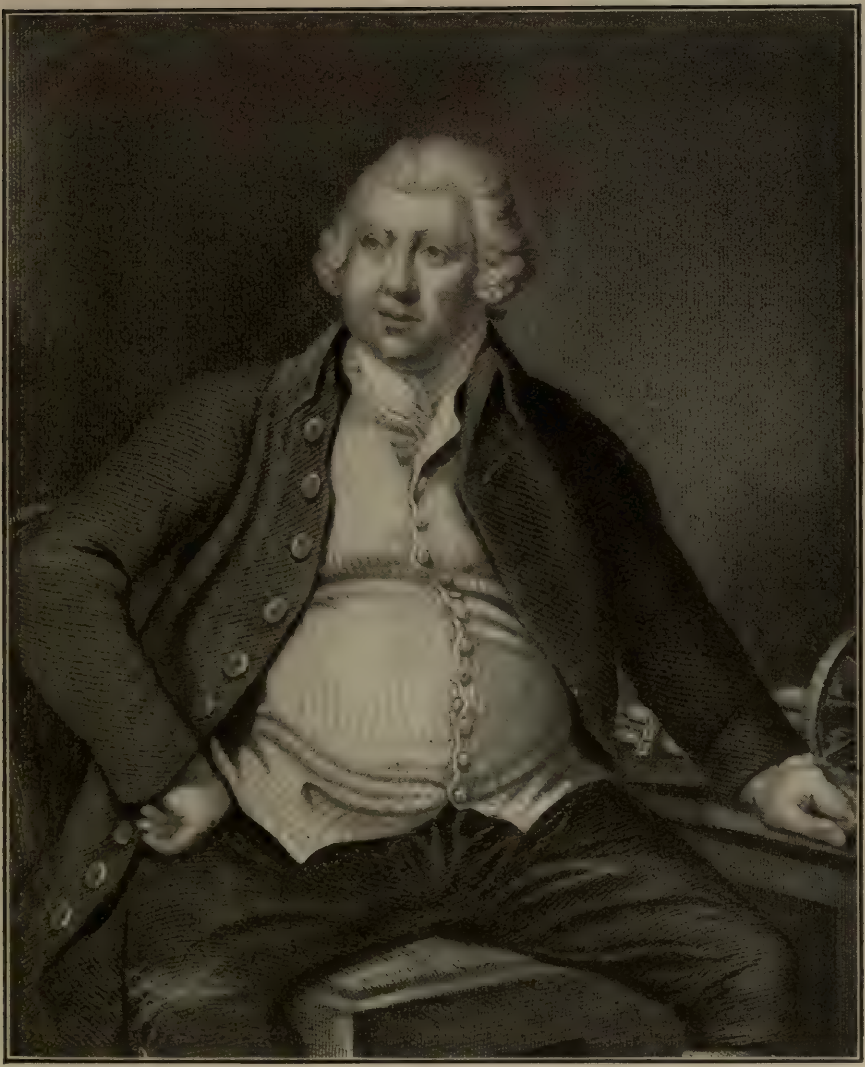
This machine, made by Sir Richard Arkwright in 1769, shows his first application of drawing rollers to cotton spinning. The roving, wound upon bobbins placed at the back of the frame, was led successively through four pairs of rollers, each pair revolving more quickly than the preceding pair, so as to draw out the cotton to a finer thread. The last pair was rotated more than six times as fast as the first. The motive power originally used with this machine was that of a horse.

publicly to acknowledge his defective schooling, as most men in his position naturally would, he may have concocted the excuse he gave, rather than admit the true explanation.

But while he had lost the first hearing in the case, he was fortunately as well equipped as his enemies for continuing the fight. And four years later, on February 17, 1785, the former decision was reversed by the Court of Common Pleas.

This decision was not final, and the case was again returned to the Court of King's Bench—the same court that had decided against him before—and the case came up for hearing in June of 1785. This time the manufacturers sprung a surprise upon the defendant. Two witnesses, a man named Highs, or Hayes, and another named Kay, were brought forward, one of whom swore that he had invented the roller spinning-machine seventeen years before, and the other that he had been employed to make this alleged machine in that year. As the defense was not prepared for this, they asked for time to prepare rebutting evidence; but the court refused this, declaring as it had before, that the specifications were too "obscure and indefinite" to warrant the issuance of a patent.

But the technical decisions of courts cannot change popular opinions and convictions. Hayes and Kay were soon forgotten, and most unprejudiced contemporaries admitted what all posterity believes, that Arkwright was entitled to full credit for the elaboration and introduction of the machine that has conferred such untold benefits upon mankind. The year fol-



SIR RICHARD ARKWRIGHT.

lowing the decision from the King's Bench, Arkwright was honored by the order of knighthood—a recognition that could not be denied him by the courts.

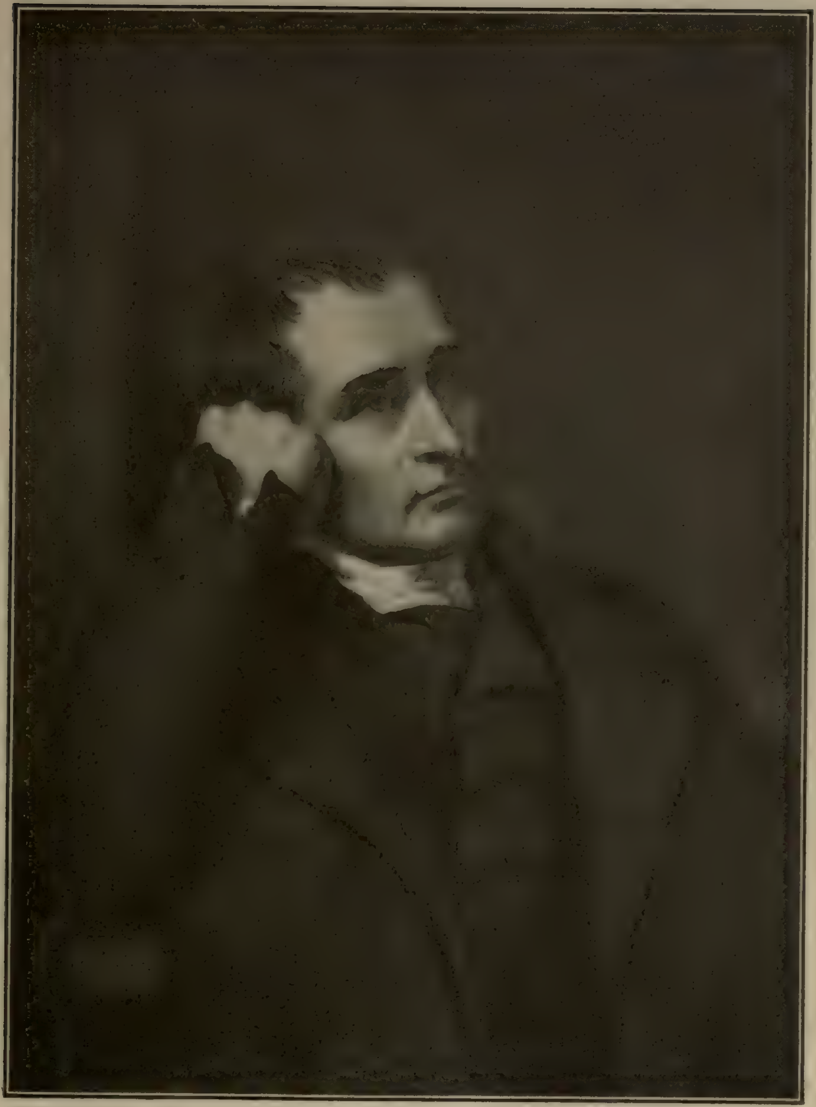
"The most marked traits in the character of Arkwright," says a biographer, "were his wonderful ardor, energy, and perseverance. He commonly labored in his multifarious concerns from five o'clock in the morning till nine at night; and when considerably more than fifty years of age, feeling that the defects of his education placed him under great difficulty and inconvenience in conducting his correspondence, and in the general management of his business, he encroached upon his sleep, in order to gain an hour each day to learn English grammar, and another hour to improve his writing and orthography! He was impatient of whatever interfered with his favorite pursuits; and the fact is too strikingly characteristic not to be mentioned, that he separated from his wife not many years after his marriage, because she, convinced that he would starve his family by scheming when he should have been shaving, broke some of his experimental models of machinery.

"Arkwright was a severe economist of time; and, that he might not waste a moment, he generally traveled with four horses, and at a very rapid speed. His concerns in Derbyshire, Lancashire, and Scotland, were so extensive and numerous as to show at once his astonishing power of transacting business, and his all-grasping spirit. In many of these he had partners, but he generally managed in such a way, that whoever lost, he himself was a gainer. So unbounded was his confidence in the success of his machinery, and in the national wealth to be produced by it, that he would make light of discussions on taxation, and say that *he* would pay the national debt! His speculative schemes were vast and daring; he contemplated entering into the most extensive mercantile transactions, and buying up all the cotton in the world, in order to make an enormous profit by the monopoly; and from the extravagance of some of these designs, his judicious friends were of opinion that, if he had lived to put them in practice, he might have overset the whole fabric of his prosperity."

THE INVENTION OF THE MULE

While the final decision of the courts against Arkwright seems unjust, it cannot be denied that this decision was enormously beneficial to commerce and humanity; for it enabled Samuel Crompton to bring forward his invention of the "mule," a spinning-machine vastly superior in many respects to either that of Hargreaves or of Arkwright. Without the inventions of these two men the mule would probably not have been conceived; but it is likewise true that until Arkwright's patents were set aside this useful invention could not have been placed upon the market without infringement.

Samuel Crompton, the inventor, was born near Bolton in Lancashire, in 1753. He was carefully raised as a boy; but his family being in poor circumstances he was obliged to support himself and earn



SAMUEL CROMPTON

his education by spinning. Temperamentally he was a great contrast to Arkwright, being a dreamer and musician, and nothing of the man of affairs that stood the inventor of the spinning-frame in such good stead.

For several years Crompton had been engaged in spinning with a Hargreaves spinning-jenny in his home, and the defects of this machine and also of Arkwright's frame were very patent to him. He therefore set about inventing a new type of machime that should combine the good qualities of both, and leave out the poor ones. Naturally, his endeavors were conducted secretly; for although he did not possess a business turn of mind, he had lived too long among the Lancashire spinners, and was too familiar with the treatment accorded Kay, Hargreaves, and Arkwright, not to know that his only safety lay in secrecy. It is said that the various parts of his machine were kept hidden in the walls and ceilings of his home when not in actual use.

The first intimation given the outside world that a new process of spinning had been discovered was by an exceedingly fine quality of cotton thread offered for sale from the Hall-in-the-Wood, Crompton's home—a quality of thread far superior to anything that could be manufactured by jenny or frame. How such thread was manufactured no one could guess, but hundreds of persons determined to find out, either by fair means or by foul. Visitors by scores came to the Hall, some of them offering to buy, others attempting to steal, the secret. Some even went so far as to bore holes in the walls and ceilings of the house in order to get a glimpse of the wonderful machine.

Meanwhile Crompton, poor in worldly goods and equally poor in a knowledge of human nature, was confronted with the fact that the limited means at his command were insufficient to pay for taking out a patent. In these straits he was induced to reveal his secret to certain manufacturers, who assured him of their intention to repay him amply later on. But these promises were not kept, and a sum amounting in all to only £60 was all he ever received for what is universally conceded the greatest cotton-spinning machine ever invented. It was not a pioneer in the field, to be sure, like the jenny and the frame, but it overcame the inherent defects of both these machines—defects that both Hargreaves and Arkwright had striven in vain to correct.

The mule derives its name from the fact that it combines many of the features of the frame and the jenny—a hybrid machine. It contains a system of rollers like those in the frame, while the twist given to the rove coming from these rollers was imparted by means of spindles in precisely the same manner as in the jenny. It must not be supposed, however, that the combining of these principles was a simple matter. In point of fact it had probably been attempted many times before; but it required the highest type of inventive genius to accomplish this, and the name of Crompton must always stand on a plane with his two great predecessors in the history of cotton-manufacture.

THE SELF-ACTING MULE

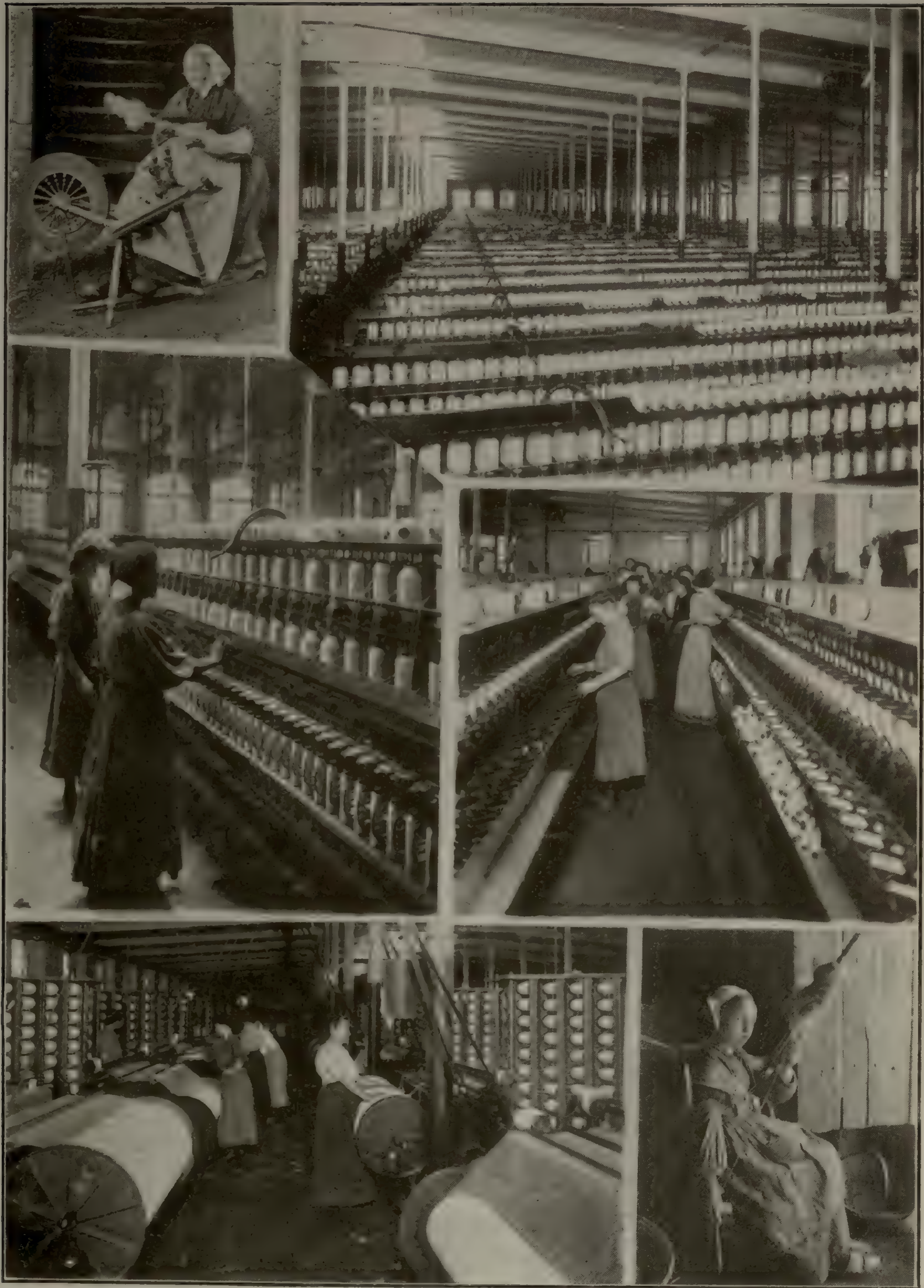
Crompton's mules were at first run by manual labor, and the number of threads that could be spun, and the amount of work accomplished, depended upon the individual strength of the workman. In 1790, however, William Kelly, of Glasgow, invented a method of running the mule by water-power, this invention increasing the annual output of spun cotton enormously. In using Crompton's mule, it was necessary to stop the machine and perform certain mechanical parts by hand. For this reason the "hand-mule" required the constant attention of one person to manipulate it, or at most one operator could tend only two machines. Attempts to construct a self-acting mule had been made as early as 1790, by William Strutt and others, but certain economic reasons operated, at that time, against its adoption, and retarded its development. About 1818, however, another self-acting mule was invented by William Eaton; and in 1825 Richard Roberts patented an improved machine for a similar purpose, thus perfecting an automatic machine which did not require constant attention.

With the improvements in methods of producing power, and with the perfection of the automatic action of the mule, the size of the machine was no longer limited to a few spindles. One of the great modern machines, having hundreds of spindles, and measuring more than a hundred feet in length, can be managed by one man, assisted by one or two boys, and performs in a day the work that required scores of men a century ago.

It should not be understood, however, that the mule immediately replaced the spinning-frame, or ever completely supplanted it in certain fields. For several years there was the keenest rivalry between the two machines, although eventually the mule obtained a considerable lead over its rival, and by the middle of the nineteenth century had completely outstripped the older machine. Nevertheless, with certain classes of work, Arkwright's frame was still superior to the mule, particularly in making strong warp threads. It found its place, therefore, in the factories, a place that could not be taken by its rival.

But the advocates of Arkwright's machine were constantly adding to, and improving the mechanism of the frame, these improved machines being known as "throstles." By these various improvements the throstle began to gain again upon its rival, and by the last quarter of the nineteenth century some improvements introduced in the Arkwright frame in America made this type of machine again popular. In the United States, the mule gradually lost ground and popularity while the new throstle gained steadily, and as the advantages of the new machine gradually became known in Europe a somewhat similar effect was produced there.

At the present time we have presented practically the same situation as regards the relative merits of these two machines that obtained a hundred years ago. The rivalry between them is just as keen now



OLD METHODS AND NEW IN SPINNING.

Four views of the interior of a modern New England Cotton Factory contrasted with the primitive method of spinning with distaff and spindle (lower figure) and with spinning wheel (upper figure). In the room shown in the upper right-hand figure there are 500 girls at work. They are invisible from this point of view because of the height of the machinery.

as it was then, and generally speaking the merits and defects of the machines are relatively the same. For general purposes the modified Arkwright spinning-machine is the better of the two; but for very delicate work it does not compare favorably with the most recent types of Crompton's mule.

II

THE MANUFACTURE OF TEXTILES

THE art of weaving, like that of spinning, was not only known prehistorically, but must have been discovered by primitive man in a very early period of his development. And such relatively highly developed nations as the early Egyptians, Assyrians, Hindus, and Chinese were good weavers at the very earliest period of their history. But it is equally true that practically every race of savages, even those living in a most primitive state, have some knowledge of weaving; while the more highly developed types, such as the natives of Mexico and Peru, were skilled weavers.

Even the most casual observation of nature must have taught primitive man the general principles of weaving. The extraordinary weaving processes by which certain tropical birds build their nests, for example, might have given man the necessary hint as to the possibility of combining fiber or hair into something resembling what we now call cloth, which could be used for wearing apparel or for other purposes if such a hint was necessary. This observation need not have been confined to the natives of tropical regions, as the observation of certain birds' nests even in temperate zones would have furnished the required information. The nests of the Baltimore oriole, for example, which remain season after season on thousands of trees all over the northern part of North America, would hardly have failed to suggest the possibilities of interlaced fibers. These nests, which are made in the form of a deep pocket, or pouch, are of sufficient strength and durability so that if a number of them were fastened together, a fairly durable protective garment could be made.

With all these object lessons to be seen in nature some observant genius among the primitive tribes would sooner or later have adopted, or attempted, the methods practised by the birds, and would thus have developed at least a rude method of weaving. Whether such an incentive actually led to the development of the art cannot, of course, be determined. Many other theories have been advanced, most of them entirely reasonable, and perhaps all of them equally true as regards certain localities.

Marsden suggests the possible Egyptian origin of weaving in the use of reeds for mattings. In this connection he says: "Conceding, and indeed affirming, that the balance of probabilities points to Egypt as the country in which weaving was first invented, it may be pointed out that in all past times, as at present, the population of that country has mainly been concentrated upon the lands bordering upon the great river Nile. From the days of the Pharaohs down to the present time, the swamps of the Nile have been noted for the abundance of vegetation they produced, and which has been applied to various uses: witness, for instance, the ark of bulrushes in which, in the days of the sojourn of the Israelites in Egypt, it is recorded the infant Moses was placed.

"What more natural than that the flags from the river should be used for floor coverings? These would be strewn about the floors of the tents and dwellings of the people, as rushes were in this country only two or three centuries ago. It would not be long before Egyptian mistresses and Ethiopian maidens would devise means of utilizing them for decorative purposes; especially as when by so doing their durability would be enhanced, and the comfort obtained from their use increased. Indiscriminately thrown upon the floor they would be trampled up, to avoid which the first plan adopted would probably be to place them longitudinally side by side. In this we get the first step in the art of weaving: a parallel arrangement of reeds and flags. The next, the introduction of transverse ones, would speedily follow, as an ornamental effect would be obtained by laying others across those first placed in parallel order.

"The second step is thus arrived at: longitudinally and transversely arranged flags; but still no weaving has taken place. As now supposed to be laid, they would be liable to derangement every time a person moved across the floor, which would destroy the ornamental effect. To prevent this it may be assumed that various expedients would be resorted to before it dawned upon any one's mind that the transverse flags should be made to pass alternately over and under those laid in a longitudinal direction, in order to secure a comparatively permanent arrangement to the mass, and such as had never been obtained before. Increased utility combined with a beautiful effect would be the outcome of this disposition of the materials, and it could not fail to strike observers very forcibly. Such would possibly, even probably, be the first woven fabric, and its conspicuous advantages would speedily secure extensive imitation and general adoption. This conjecture, it may be observed, is based on a substratum of fact."

In every country the amount of weaving must depend of course upon the amount of spinning, or cotton and wool products that are manufactured in, or imported into, the country. For obviously the weaver cannot work unless he has threads or yarn to work with. Until the beginning of the eighteenth century the balance of production of spinning and weaving was practically equal in England and Western Europe, both spinners and weavers producing their products by manual labor only. In the seventeenth century, however, England began extensive trading with India, and the English merchantmen returning from the Orient began bringing into Great Britain quantities of cotton cloth made by the Indians. This importation soon threatened the English spinning and weaving industries, and was restricted by legislation at the beginning of the eighteenth century. But these laws had only a restricting effect, without absolutely stopping the traffic, and they fell very far short of solving the problem of overproduction by the spinners. The weaver was unable to weave the yarn as fast as the spinner could make it.

JOHN KAY AND THE FLYING SHUTTLE

What was needed was some device for weaving cloth more rapidly, and as is usual in such cases of necessity, an inventor soon appeared whose invention revolutionized the weaving industry so completely that the market, instead of being overstocked with cotton yarn, was quickly depleted, the new weaving-machines consuming the supply faster than it could be produced. The inventor of this new weaving-machine was John Kay, an Englishman, and his invention was the famous flying shuttle, invented in 1738.

This machine did for weaving what Hargreaves' spinning-jenny did for spinning—it doubled and quadrupled the power of the weaver. In the older looms in use before the time of Kay's invention, the operation of weaving was performed by two men working at a single loom, one man throwing the shuttle carrying the weft thread across the warp threads while the other man caught it in his hand. In the flying-shuttle loom the work of catching the shuttle was done mechanically, one man being thus enabled to work the loom without assistance. As the second man was no longer required, he, too, could take charge of a loom and thus the weaving output be doubled. The principles involved in this machine were practically the same as those in modern looms, although it has taken the efforts and genius of an army of inventors since Kay's first invention to produce the wonderful modern loom.

Reference has been made in the preceding chapter to the hostile reception given this wonderfully useful invention by the fellow countrymen of Kay; how they rose against him, smashed his machines and workshop and drove him from the county. He was more graciously received in other parts of the country, however, although he never realized any material gain from his invention and died in straitened circumstances a few years later.

One of his sons, Robert Kay, who inherited the inventive genius of his father, devised what is known as the "drop-box," in 1760. This is an arrangement of several boxes whereby a weaver could insert several colors as stripes across the length of his loom with great facility. By arranging the warp threads in alternating colors it was possible by this method to weave checkered effects as easily as single-colored ones. The principle involved in this invention is still in use, and thus John Kay and his son Robert may justly be considered the originators of modern weaving processes.

THE DEVELOPMENT OF THE POWER-LOOM

The first attempt at inventing a successful power-loom, or one approaching practicality, seems to have been made by M. de Gennes, an officer in the French Navy. He sent suggestions for such a machine to the Academy of Sciences in 1678, and although it has since been determined that these specifications contained the germ of an idea of a power-loom, nothing of any practical importance came of them. Almost a century later, a countryman of De Gennes M. Vauconson, made a similar attempt to produce a power-loom; but his efforts were made in that most inauspicious time at the middle of the eighteenth century, when Kay's flying shuttle had made the hand-weaver able easily to outstrip the spinners. In fact, many looms were forced to stand idle part of the time because of the inability of spinners to supply yarn. With the inventions of Hargreaves and Arkwright, however, these conditions were reversed, and by the closing years of the century there was an overproduction of spun products which could not be handled by the ordinary looms.

It was at this period, in 1784, that the attention of a certain Dr. Edmund Cartwright, clergyman of the Church of England, was directed to the problem confronting the weavers. This remarkable man, without ever having seen a weaver or a loom at work, and never having attempted anything in the field of mechanics before, soon produced the first ancestor of the power-loom, whose modern descendants are among the most remarkable of all ingenious machines.

In the history of scientific discovery and invention there are other instances where the temperament of a poet has been combined with the practical mechanical application of the mechanic, and wonderful discoveries and inventions have been the result; but perhaps nowhere is this exemplified better than in the case of Doctor Cartwright. Educated at Oxford in University College, and fellow of Magdalen College in 1764, his life had been spent in fields far removed from that of practical mechanics. Writing poetry and preaching were his occupations, and at both he had succeeded well. At forty years of age he was well known for his *Armiul and Eloira*, a legendary tale in verse which passed through some seven editions in a year, and for *The Prince of Peace*, a poem of considerable merit. Two years later he was far better known as one of the world's great inventors. The story of this invention has been told by Cartwright in a letter written to his friend Bannatyne, in which he gives a vivid picture of the circumstances that induced him to enter the field of mechanics.

"Happening to be in Matlock in the summer of 1784," he wrote, "I fell in company with some gentlemen of Manchester, when the conversation turned on Arkwright's spinning-machinery. One of the company observed that as soon as Arkwright's patent expired so many mills would be erected, and so much cotton spun, that hands never could be found to weave it. To this observation I replied that Arkwright must then set his wits to work to invent a weaving-mill. This brought on a conversation on the subject, in which the Manchester gentlemen unanimously agreed that the thing was impracticable; and in defense of this opinion they adduced arguments which I certainly was incompetent to answer, or even to comprehend, being totally ignorant of the subject, having never at that time seen a person weave. I controverted, however, the impracticality of the thing, by remarking that there had lately been exhibited in London an automaton figure which played at chess. 'Now you will not assert, gentlemen,' said I, 'that it is more difficult to construct a machine that shall weave, than one which shall make all the variety of moves which are required in that complicated game.'

"Some little time afterward a particular circumstance recalling this conversation to my mind, it struck me that, as in plain weaving, according to the conception I then had of the business, there could only be three movements, which were to follow each other in succession, there would be little difficulty in producing and repeating them. Full of these ideas, I immediately employed a carpenter and smith to carry them into effect. As soon as the machines were finished, I got a weaver to put in the warp, which was of such material as sail-cloth is made of. To my great delight, a piece of cloth, such as it was, was the product.

"As I had never before turned my thoughts to anything mechanical, either in theory or practice, nor had ever seen a loom at work, or knew anything of its construction, you will readily suppose that my first loom was a rude piece of machinery. The warp was placed perpendicularly, the reel fell with the weight of at least half a hundredweight, and the springs which threw the shuttle were strong enough to have thrown a Congreve rocket. In short, it required the strength of two powerful men to work the machine at a slow rate, and only for a short time. Conceiving, in my great simplicity, that I had accomplished all that was required, I then secured what I thought a most valuable property, by a patent, 4th of April, 1785. This being done, I then condescended to see how other people wove, and you will guess my astonishment when I compared their easy modes of operation with mine. Availing myself, however, of what I then saw, I made a loom, in its general principles nearly as they are now made. But it was not till the year 1787 that I completed my invention, when I took out my last weaving-patent, August 1st, of that year."

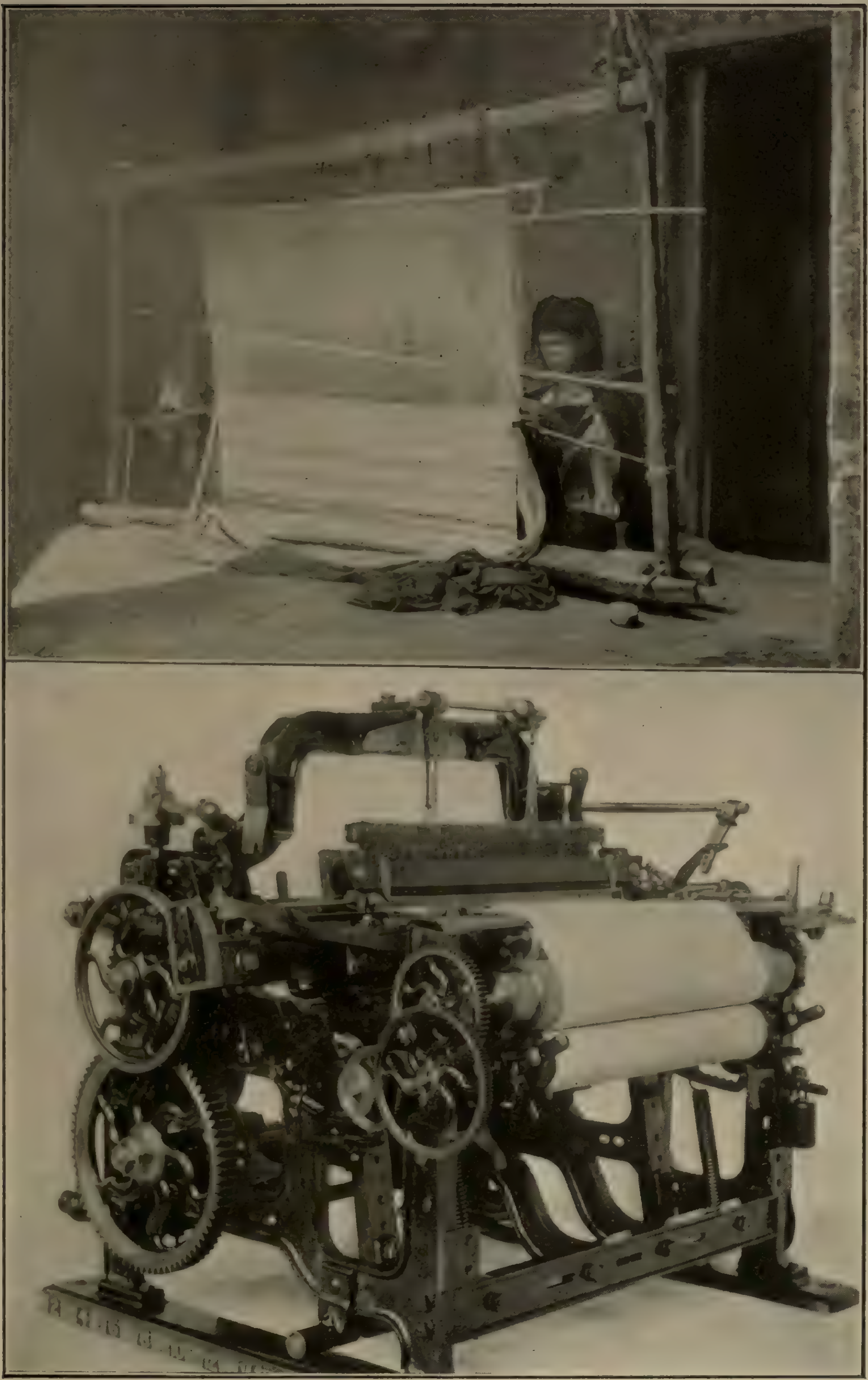
A VERSATILE INVENTOR

Naturally the man who could make one such revolutionary invention could not stop at that, and Doctor Cartwright followed up his first invention with many others. Patent packings for steam-engine pistons, combining-machines, bread-making, brick-making, and rope-making machines followed quickly. None of these served such useful purposes as his first great effort, and they netted him in the end a vast amount of profitless unhappiness, his patents being constantly infringed. For the spirit of opposition to mechanical contrivances for lessening labor still remained as dominant among British workmen as it had in the time of Kay and Hargreaves, and when in 1791 Cartwright succeeded in finding an honest manufacturer willing to use his looms and pay a royalty, the factory containing the machines was burned and destroyed by an incendiary. Meanwhile, his patents of all kinds were infringed without redress everywhere, and though late in life he received a grant of £10,000 from Parliament, this was small recompense for the money he had spent, to say nothing of his years of labor and struggle.

THE POWER-LOOM PERFECTED

Cartwright's first loom, which according to his own letter quoted above was a very crude affair, nevertheless contained the essential principles of the modern power-loom. In his specifications for his patents he describes these essential features as follows, "The shuttle, instead of being thrown by hand, is thrown either by a spring, the vibration of a pendulum, the stroke of a hammer, or by the application of one of the mechanical powers, according to the nature of the work and the distance the shuttle is required to be thrown, and, lastly, the web winds up gradually as it is woven." Then follow other details which constitute the complete process of manufacturing cloth. The power for running this machine was imparted to a roller by means of a crank and handle.

His first machines, as we have seen, were defective in certain things, and Cartwright set about perfecting and completing every feature and combating mechanically every difficulty that might arise in the process of weaving. His visits to the places where practical weaving was being done had shown him the defects and possible weakness of his machine, and furnished him with many new ideas. The result was that by 1786 he had perfected plans for an absolutely automatic power-loom, almost as complete in every detail as the most perfect loom of to-day. This machine not only provided for automatically handling the shuttle, but for "warping, beaming, sizing, taking-up motion for cloth, letting-off motion for warp, stopping



PRIMITIVE AND ADVANCED METHODS OF WEAVING.

The upper figure shows a modern Algerian weaving cloth. The lower figure presents a modern weaving machine, which, without the introduction of any new principle, performs the operation of weaving with enormously increased speed, and produces a cloth much more uniform in texture.

motion for broken warp and weft"—in short, several things that are hardly practicable in the highest type of modern loom. But this wonderfully complete machine was at least a century ahead of its time in many features, and was not a practicable success, although Cartwright's more simple looms were soon installed all over Great Britain, quickly equalizing the momentary advantage in production gained by the new spinning-machines.

THE JACQUARD LOOM

The closing years of the eighteenth century and the opening years of the nineteenth saw an army of inventors in the field improving the power-loom. Some of these improvements were extremely useful, and some of the inventors deserve more than passing notice. Among these was the Frenchman Joseph Marie Jacquard, modifications of whose invention, the "Jacquard loom," are still responsible for the weaving of most elaborate modern pattern fabrics.

Jacquard was born July 7, 1752, at Lyons, the great silk-manufacturing center of France. Although raised in an atmosphere of weaving, his father and mother both being engaged in that trade, young Jacquard became interested in bookbinding, afterward turning his attention to type-founding, and still later to the manufacture of cutlery. On the death of his father, however, he came into possession of a small cottage and a silk-loom, and as his other ventures had not proved particularly successful, he returned to his ancestral home and entered the silk-weaving trade.

His experience in other forms of manufacture soon led him to appreciate the shortcomings of the ordinary power-looms then in use, and as early as 1790 he seems to have invented, and brought to something like practical form, his now famous loom. At this time all France was involved in the Revolutionary War and Lyons was one of the centers of activity. Jacquard and other members of his family left their looms to fight against the forces of the Convention. In one of the battles against these armies his son was killed while fighting at his side, and this is said to have determined Jacquard to renounce the profession of a soldier and return again to his loom.

By the beginning of the nineteenth century he had perfected his invention of a loom for weaving, and in 1804 he exhibited his new machine, and was given a bronze medal by the National Convention. About the same time he received prizes at home and in England for the invention he had made with which fish-nets could be woven quickly and cheaply.

Having gained this success Jacquard returned to Lyons and succeeded in interesting several manufacturers in his new looms. The utility of his invention was so apparent that he was allowed to install several of his machines in the factories of the neighborhood. But the weavers themselves did not receive his invention in the same spirit as the factory owners, and shortly after several of his machines had been installed, a mob of workmen attacked the factories in which they were being used, tore them from their frames and made bonfires of them in the streets. Jacquard narrowly escaped with his life, being smuggled out of the neighborhood by friends.

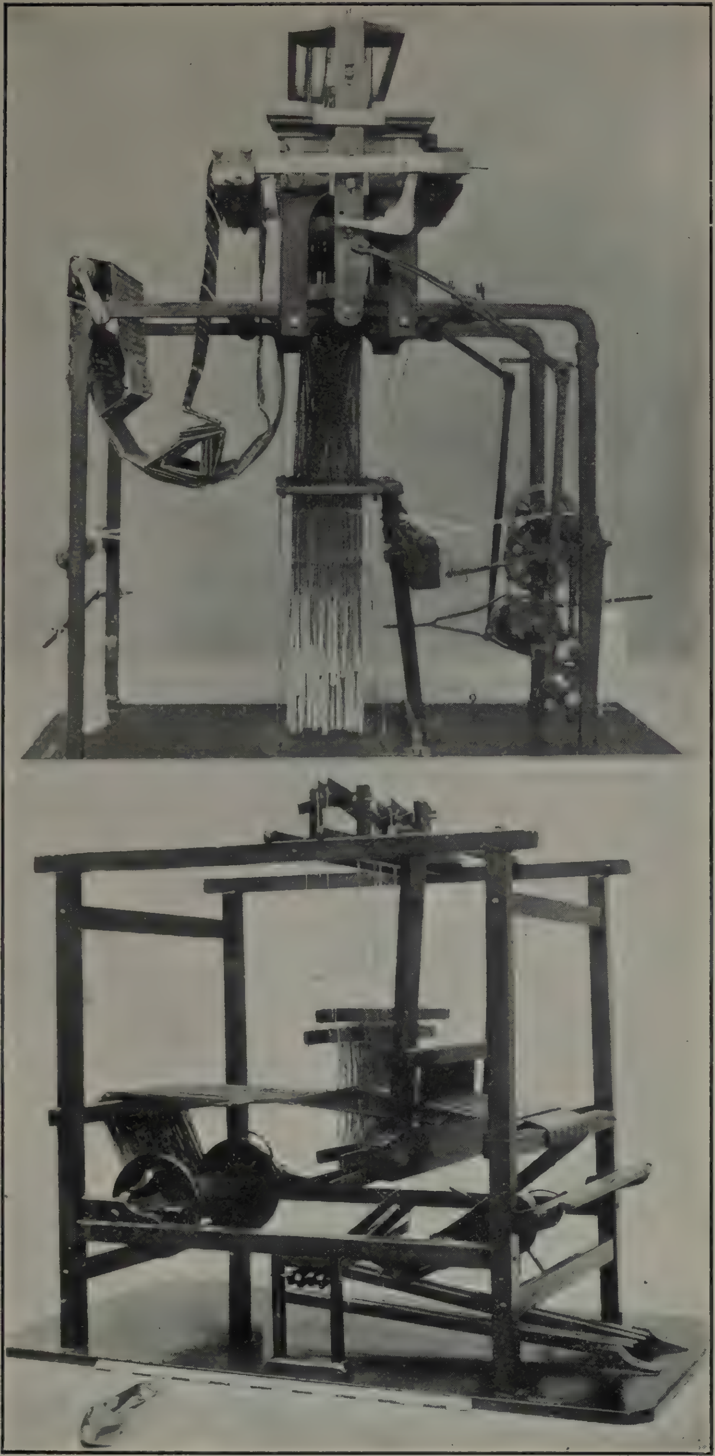
While the French mobs, like the English, might destroy the new machines, they could not destroy the ideas involved; and the value of Jacquard's invention had been too thoroughly demonstrated to allow its suppression by localized acts of violence. Other similar machines were soon produced, and before the end of the first quarter of the century, the Jacquard loom was in general use, not only in France, but in every country where extensive weaving was done. While the inventor never realized the same financial gain from his invention as did the more fortunate Arkwright in England from his spinning-machine, he at least fared better than Hargreaves, and spent the last years of his life in apparently comfortable circumstances. He died in 1834 in a place near his native home, having returned there a few years after the destruction of his first loom.

One of the great problems to be overcome was that of producing a loom that would supply a full bobbin of yarn to the empty shuttle, or replace an empty shuttle with a full one, without stopping the machinery. But despite the efforts of numerous inventors this was not accomplished in practical form until 1894, when the Northrop loom was invented. This machine is made with a magazine which is kept filled with full bobbins, and by an ingenious mechanism automatically forces out the empty bobbins and replaces them without stopping or retarding the weaving. At present this loom can be used for weaving the simpler kinds of cotton fabrics only, but its popularity is shown by the fact that some seventy thousand of these looms were put into operation during the first decade of the invention. Attempts are being made constantly to perfect this loom for more complicated weaving, and it is probable that this will be accomplished in the near future.

For complicated weaving the Jacquard loom is still the one in universal use, the modern looms of this type adhering closely to the principle of the original invention. Like the modern power-loom this machine is altogether too complicated to be understood from a description, but the secret of the pattern weaving with this machine lies in the use of peculiar paper-card patterns which guide the needles, and with which the ordinary workman can produce the most beautiful effects in a comparatively short time. Generally speaking, the more complicated the pattern to be woven the greater the number of cards that must be used, but once these cards are made the weaving can be done very quickly, and there is practically no limit to the number of patterns that can be produced. In some very elaborate designs as many as thirty thousand separate cards have been used, although the use of this extraordinary number is unusual.

FINISHING TEXTILE FABRICS

With the Jacquard loom it is possible, as already pointed out, to weave complicated patterns, the threads employed being of course dyed to the various shades required before being placed in the loom. With many varieties of material, however, the more economical method is employed of printing the pattern on the



MODELS OF A PRIMITIVE LOOM AND A JACQUARD LOOM.

The lower figure shows the structure of the primitive weaving apparatus, which employs the same principles that are utilized in the modern power loom. The upper figure shows the remarkable apparatus invented in 1728 by the Frenchman, Jacquard, with the aid of which complicated patterns are woven. A chain of punctured cards determines the pattern. The loom to which the Jacquard machine is attached in the above model is weaving a narrow silk ribbon.

finished cloth. This is particularly done in the case of certain cotton goods, notably the calicos. These goods are also frequently treated with various so-called sizes to give them weight and body, and sundry processes of calendering—which may be roughly likened to ironing—are employed to give them a smooth surface. Beetling is a process by which a cotton fabric is rendered softer and at the same time more impervious, usually by some form of drop hammer or stamp, but sometimes by rollers having a checkered surface.

The printing of these goods was formerly accomplished with the aid of wooden blocks carved much after the manner of wood engravings for the reproduction of pictures. The blocks were furnished with color by placing them face downward on a cloth stretched on a frame which floated on gum water, and on this cloth the printer continuously brushed the required color. When the pattern required additional colors, these were supplied successively by different blocks. It was not unusual, however, for the printer to use a chemical mixture known as mordant which acted on the dye when the article was subsequently immersed in the dye vat. White spots were sometimes obtained by printing them with wax before dyeing, so preventing these spots from absorbing the coloring matter. In modern calico printing, however, rotary machines are almost entirely employed, the pattern being engraved on the copper surface of the roller, and the impression taking place when passing between the printing and platen rollers, the process being essentially that employed in ordinary printing processes for the production of books or newspapers.

Woolen goods are usually made from yarns dyed before weaving, and the finishing process applied to the cloth is altogether different from that used in the case of cotton fabrics. Here it is often desired to obtain a finish that hides the individual threads of the warp and weft. This effect is produced by the stray ends projecting from woolen threads, these ends in the woven material when brushed or treated with hot water matting together and forming a nap that conceals the individual threads. The surface of any ordinary piece of new woolen goods shows this effect; and equally familiar is the fact that when the nap wears off the threads reappear, the cloth becoming literally threadbare.

The process employed from an early date for thus finishing the surface of woolen goods is a simple but peculiar one. It is dubbed "teasing" because the essential apparatus employed in the process consisted of the prickly seed balls of the teasel plant, which are covered with minute hooks and hence are admirably adapted to open and loosen the uppermost fibers of the wool when drawn over the cloth. Originally the teasels were set in a frame which was rubbed over the cloth by two men, but subsequently the more convenient method was devised of arranging the teasels on a cylindrical drum, so constructed in connection with other cylinders that the cloth could be passed and repassed over it by the action of a belt or other gearing. This apparatus constitutes a teasing or gig mill.

Whether the natural teasel or an artificial substitute—bearing the same name—is employed, the process constitutes essentially, as already noted, a repeated scratching of the surface of the cloth; but the final result is determined partly by the extent to which the teasing process is carried out, and partly by the original quality of the woolen thread itself. The difference between worsted threads and woolens proper has already been pointed out; and the different appearance of goods that have been subjected to the action of the teasing mill from those not so treated is familiar to every one, though the method that accounts for the diversity may not be so commonly understood.

LACE MAKING AND KINTTING MACHINERY

It remains to say a few words about a class of textiles of an entirely different type from those hitherto considered,—those, namely, produced from the continuous inter-looping of a single thread, without the employment of weft or warp threads. The familiar examples of this process are nets, laces, and garments produced by crocheting and knitting. A well-known peculiarity of a knitted garment is that the cloth, being free from warp threads, is extensible in any direction, adapting itself to the contour of the body in a way not to be expected of a woven fabric.

Although net-making and various types of lace-making have been practised from antiquity, it is a rather curious fact that the simple processes of crocheting and knitting are of modern origin, having originated, it is believed, in Scotland no longer ago than the fifteenth century. It is doubly curious that whereas this simple process of knitting with four parallel sticks or wires known as knitting needles, operated by hand, was invented at so relatively recent a period, yet a complicated machine known as the stocking frame, which knits mechanically, was invented in 1589, almost two centuries before the development of the weaving machines of Hargreaves and his successors. The inventor of this first knitting machine was the Reverend William Lee. He introduced from the outset the fundamental principle of a successful knitting machine, correctly conceiving that a separate needle should be used for each loop. "In this way he at first made flat webs which by being sewn together along their selvedges made a cylinder. He afterwards found the means of producing shaped articles by throwing out of action some of the hooks as required. Lee, failing to get support in England, took his machine to France where he successfully settled at Rouen, and in 1640 his frames were adopted in Leicester.

"The knitting by machinery of the ribbed surface, which gives so much greater elasticity in one direction, was first accomplished by Jedediah Strutt in 1758 by the introduction of a second set of needles at right angles to the first set. The circular knitting machine by which cylindrical work could be produced without seams was brought into a form suitable for practical use in 1845 by Mr. Peter Claussen, but such an arrangement had been suggested much earlier.

"The needles in a stocking frame or knitting machine have hooked ends, with the hook extending backwards to form a long spring barb or 'beard' which is capable of being pressed close to the body of the needle, so that the loop of thread on the needle can be pushed over the hook when the beard is depressed, or will be retained on the hook if the beard is up. In this way the loop in the hook is drawn through the loop that has been formed round the needle. In 1858 Mr. M. Townsend introduced the 'latch-needle,' in which the beard is replaced by a finger hinged to the needle; this arrangement simplifies the work of the machine, and the small knitters for domestic use usually have needles of this type. It has been stated that a hand knitter can work 100 loops a minute, that Lee's machine did 1,000 to 1,500 loops, and that the circular frame does from 250,000 to 500,000 per minute.

"Knitting is one of the few industries in which the factory system has not completely displaced home industry, and the tendency seems to be to extend the employment of small machines worked by hand or treadle at the operator's home, rather than the larger installations of a factory. The knitting and hosiery industries are now of the greatest importance, and include the manufacture of underclothing, caps, stockinet cloth, etc., while the bags or 'shirts' in which frozen meat is shipped, and the little mantles for the Welsbach burner, are examples of the varied application of this interesting process." These industries, however, are of course of minor importance as compared with the production of woven textiles.

III

THE STORY OF COSTUMES

IF ONE examines the mode of dress that held with certain races even in the very earliest times and compares the costumes of that period with the costumes of to-day, one is struck with the relatively small departure that has been made, at least as regards the general types. Not that the digressions have not been great enough in some of the intervening centuries between the dawn of history and the present time, as during certain periods of the Middle Ages when comfort and convenience were not considered in the costumes worn. But this is a practical age, and it was necessarily a practical age when clothing was first worn, and our clothes just at present are designed along practical lines as were those of our remote ancestors. And thus we have almost completed the cycle, and returned to the simple type of garment worn by our most remote civilized ancestors in the cooler regions.

If we go back and examine the kind of clothing of that most remote ancestor who lived near the Equator before he had developed sufficiently to begin conquering the colder regions, we should find him first with no protective clothing at all, then gradually protecting body and limbs with skins, and later with woven cloth. But the clothing of this man need not concern us here. Our interest begins when he started on his migrations into cooler regions and was obliged to adopt some form of clothing more convenient than loose skins wrapped about his shoulders or around the waist. For this northern dweller is the one largely responsible for our modern form of clothes and dress.

So long as civilization centered in tropical regions where dress for protection against the inclemencies of the weather was unnecessary, such as the regions of the Nile, there was little advance toward our modern form of dress. But while the Nile dwellers were still wearing the flowing garments that so little resemble modern clothes, there were undoubtedly races of barbarous men in the wilderness lying to the north, who were wearing garments closely resembling our modern coats, trousers, shoes, gloves, and hats.

The idea represented in these garments was that of combining the greatest amount of freedom for the limbs with the maximum protection. For this purpose jackets, or shirts with sleeves, and trousers not unlike modern ones were used centuries before they were worn by more southerly races. And that these northern barbarians had solved the problem better than their more enlightened southern neighbors and the Oriental races, is shown by the tendency of modern practical forms of clothing. For although it has taken millenniums to convince certain Oriental nations that garments consisting essentially of jacket and trousers more nearly meet the requirements of active men than any other type, the fact that this is true is now shown by the general tendency to-day of all nations to clothe their soldiers in such costumes. Nearly every practical soldier in this practical age, whether he be a Japanese, Hindu, Turk, or roughrider, wears a costume in the main consisting of the essential garments of the costume worn at the dawn of civilization by the northern races.

In short, the Oriental races have been forced to admit the superiority of the practical Western costumes, this admission being tacitly shown by their adoption. Yet the interval between the time of this first simple costume and the return to it in a general way at the present time, is filled with more fantastic departures than can be found in almost any other field of history.

Undoubtedly, two very important factors have figured preeminently in this development—military methods, and fashion. The first of these is the more easily understood and explained. The second has usually been, and still is, inexplicable, although not always so in certain instances. And even in military costumes fashion has made itself felt in every stage and phase of progress.

In the ages when the common weapon, the sword, was carried at all times for protection, costumes that permitted free use of it should have been the prevailing ones. But this was not always the case, even jeopardy to life itself being sacrificed to fashion. It is only in very recent years that convenience alone has been considered in the dress of the soldier in active service;

and except in times of war this is still not the only consideration.

Nevertheless we are undoubtedly progressing from the complex to the simple, just as our ancient ancestors progressed from the simple to the complex.

SOME CURIOUS FASHIONS EXPLAINED

As was said a moment ago the caprices of fashion are usually inexplicable; such, however, is not always the case. Some fashions have been established for very definite reasons. Thus the custom of wearing long-pointed shoes, which remained popular for several centuries, resulting in the most grotesque and inconvenient footwear imaginable, originated with Count Fulk of Anjou, who sought to hide his deformed feet. Being afflicted with bunions he sought to cover his misshapen members by wearing extremely long, pointed shoes. What the count did, his followers must do; and hence the resulting grotesque and inconvenient fashion in shoes.

Richard III of England, being deformed, wore garments padded and puffed to hide his deformity, and this fashion was adopted and elaborated by his courtiers. And it is more than likely if we could but fathom the secret, that numerous other absurd fashions originated in some subterfuge to conceal bodily defects in some pampered leader of fashion.

Once a thing became fashionable, it was no easy matter to break the established custom, no matter how foolish or inconvenient it might be. Hoop-skirts, for example, remained in use for a good part of two centuries despite reasonable arguments, satire, and ministerial condemnation, and have only fallen into disuse in our own generation.

The Church was continually preaching against extravagance in dress, particularly during the seventeenth and eighteenth centuries, without any effect whatever; and occasionally a monarch took a hand, and even set an example for his subjects. The "merry monarch," Charles II, attempted to change the ridiculous fashion of his time by adopting a plain type of dress not unlike the modern suit, declaring that he should wear no other style during the remainder of his life. Despite the secret smiles of his courtiers he kept his word for some time. Then his luxurious neighbor across the channel, Louis XIV, heard of Charles's decision, and promptly adopted the English monarch's costume as livery for his servants. This was too much even for a reformer; and Charles quickly surrendered and returned to his former costumes.

In England, at least, the plagues were responsible for some changes in fashions, and for the continuance of fashions in vogue, and a tendency to simplicity in dress. The great plague of 1665 almost completely depopulated certain districts of London, some well-worn thoroughfares being so deserted that grass grew in the streets. It came to be generally believed at that time that imported garments were the cause of infection, and even fashionable gallants became chary of purchasing new clothes. The result was that tailors were obliged to close their shops, and some usually well-groomed men wore their old suits until they were as shabby as beggar garments. When they were finally obliged to buy they bought sparingly from well-known sources, and this tended to simplify the cut of garments by curtailing the amount of uninfected cloth obtainable.

In a much less degree the plagues affected the wearing of wigs. For although it was believed, probably with good reason, that many of the wigmaker's products were made from hair clipped from the heads of plague victims, human vanity was such that even risking death itself was preferable to exposing gray hairs, or no hairs at all. Men could bear excusably aged garments better than the inexcusable marks of bodily age; and so wigmakers flourished despite the plagues, while their tailor neighbors starved.

But the heyday of the wig was the eighteenth century. In that age they were no longer confined to the small affairs made to match and conceal crowns of hair, or simply to hide gray locks, but were made more as hoods and hats, and worn by all well-to-do gentlemen. A gentleman would feel as ridiculous without his wig at that time as one would now without a collar.

The custom of powdering the wig is said to have originated through the whims of some French buffoons. A troop of these performers, wishing to make themselves as grotesque as possible, covered their wigs with flour. This caught the fancy of a bevy of rollicking French gallants, who imitated the buffoons, and soon established a custom which came to be regarded in all seriousness. Delicately scented powders soon replaced ordinary white flour, and great powdered and perfumed headpieces, costing sometimes three hundred dollars or more, came to be part of the dress of every well-groomed gentleman.

These costly adornments soon became the marks of thieves and purse-snatchers, who wrought havoc among the wig-wearers in the narrow London and Paris streets. Instead of being in danger of having his pockets picked, a man was in constant fear of having his wig snatched. In no place was he entirely safe. If he rode in a closed coach the clever thief might mount the rear axle, cut dexterously through the back curtain, and extract a wig by a single jerk. If he passed along the streets at night a fish-hook dangling from some house-top might free him of his hat and wig at one haul. And if he sat near an open window on the street he was in constant danger from long arms or still longer poles with hooks attached.

A very common method employed by the thieves for carrying on their trade was to assume the rôle of bakers, carrying large baskets on their heads or shoulders. In the basket was concealed a small but nimble-fingered boy whose business it was to dart out his hand at the right moment and remove the wig of some unfortunate passer-by.

THE FOLLIES OF FASHION

It is difficult to select any one period and point to it as the one of preeminently ridiculous fashion in dress, since even the nineteenth century was guilty of many follies in this direction, if not quite equalling some of the preceding ones. But in many respects the age of Queen Elizabeth and Shakespeare—the age of the "ruff"—is quite the most remarkable. And in this craze for ruff-wearing, as in many other crazes in preceding centuries, the men were more at fault than the women.

About the middle of the sixteenth century French gentlemen began to wear collarettes, or frilled ruffles, and the fashion soon spread all over the Continent and across the Channel to England. A few years later and the wide ruff characteristic of the Elizabethan period was in full sway. Henry III of France wore ruffs something over a foot in depth, which contained more than nineteen yards of cloth.

In such a ruff Henry and his courtiers could move their heads very little, and eating and drinking without soiling it were difficult feats. Special table utensils were necessary, such as long-handled spoons, some particularly full-beruffed ladies using special spoons two feet long for taking their soup. These great ruffs were supported by small irons and wires, holding the three, four, or five rows of lace in place, the last row appearing above the top of the head.

Later the use of starch was introduced and this gave a fresh impetus to ruff-wearing. Where the custom originated cannot be definitely determined, but it came into the household of Queen Bess through the wife of her Dutch coachman, who understood the art of starching. This thrifty housewife was soon starching the ruffs of all the fine ladies of London—and accumulating a fortune by it. She starched ruffs white or yellow at discretion, yellow being a very popular color until a certain Mrs. Turner, who had poisoned Sir Thomas Overbury, thoughtlessly wore a yellow ruff on her way to execution. This decided the fate of yellow ruffs, as wearing them thereafter was thought too suggestive.

The custom of ruff-wearing came in for as full a measure of condemnation by "censors of public morals" as any one fashion ever adopted. Yet such condemnation met the same fate that arguing or preaching against any fashion usually meets. The great ruff went out of use when capricious fashion, for some unknown reason, dictated that it should. "No fashion has ever been preached down in England by moralists," says a writer, "and the ruff held itself erect through all condemnation, never unbending its stiffness or yielding an inch of its width for any censure. Indeed, the law, unless upheld by physical force, was powerless against the ruff."

In Spain, the fate of the ruff, which in the days of Philip III had become enormous and costly,—"perhaps the most extravagant article of dress ever generally and diurnally worn in any country"—was one of those matters for royal interference to which we referred a moment ago. Philip IV, in 1623, issued pragmatics suppressing it, and decreed as alternatives either the plain linen band or the flat Walloon collar falling over the shoulders. Both of these articles were utterly rejected by the splendor-loving Spaniards, and the problem now became one of finding a new collar that would be dignified and stiff without the forbidden starch "or other alchemy," for so the pragmatics read.

A clever Madrid tailor finally appeared one day before the king with a wide-spreading construction he had made of cardboard, covered with silk on its inner surface and with cloth on the outer. The cardboard had been ironed and shellacked to give it a permanent shape. The new collar looked well and it was certainly an economical neck-gear, so Philip, well pleased at his subject's ingenuity, ordered some from the happy tailor for himself and his brother.

"But alas!" says an authority on Spanish history, "the pragmatics had forbidden 'any sort of alchemy' to make collars stiff, and moreover, the Inquisition was soon told by its spies that some secret incantations, needing the use of mysterious smoking pots and heated machines turned by handles, were being performed by the tailor in the Calle Mayor."

Here was trouble indeed for this humble maker of fashions. He was haled before the dread tribunal, and was most lucky, as he thought, to escape with having his stock and implements burnt before his door.

It is needless to say that the President of the Inquisition was severely censured when the matter came to the king's attention, and the tailor once more set to work.

His new creations were promptly called "gollilas" and were worn at once by the men of the royal family and their many courtiers.

"Thenceforward," continues Hume, "all Spain, Spanish Italy, and South America wore gollilas, the curve, size, and shape changing somewhat as other fashions changed, but the principle remained the same, until Spain was born again and a French king banned the gollila as barbarous and imposed upon his new subjects the falling lace cravat and jabot of the eighteenth century."

KNITTED GARMENTS

The time of the first introduction of knitted stockings, whether of silk, wool, or cotton, is unknown. As elsewhere noted, the art of knitting was seemingly an invention of the fifteenth century. Some articles called "silk hose" are recorded among the effects of Henry VIII, and by some this is interpreted as meaning knitted stockings. If such were the case, this is perhaps the first record of such stockings being worn in England, and France was not in advance of her neighbor in this respect. It is probable that such stockings were worn in Spain some time before, and by the time of Elizabeth they had come into general use.

Thus every part of the modern garment had been evolved, and from the sixteenth century onward the changes that occurred were simply modifications in form. The modern starched linen collar, cuff, and shirt-front are direct descendants of the starched ruffs made famous by the wife of Queen Elizabeth's coachman.

Stockings and knit undergarments are simply developments of the silk hose of Tudor times. The one garment that appears to have come down with fewer modifications than any other through the ages seems to have been the woman's skirt. Not but what this was modified and changed constantly, but the general contour remained the same, from the garment worn by Egyptian, Greek, and Roman women, through the Middle Ages down to the present time.

The striking contrast between the gaudily dressed gallant during the centuries of display attire and his surroundings, is shown in the reversal of these conditions at present. The modern well-dressed gentleman lives in a dwelling quite in keeping with his garments; or rather, the luxuriousness of his surroundings far exceeds that of his attire. In past centuries these conditions were reversed. In the Middle Ages the gentleman dressed better than a modern prince and lived in surroundings inferior to those of a modern workingman. With smoking fireplaces and dripping lights, dirt floors strewn with rushes, and without even necessary articles for the toilet, how did the gaudy, silk- and velvet-covered creatures manage to keep themselves and their finery clean? There can be but one inference: they didn't.

SOME REMARKABLE COSTUMES

If an attempt were made to describe, even casually, anything like a representative list of the extraordinary costumes worn at various times during past centuries, volumes would be required. In fact, there are many-volumed works dealing with this subject in existence.

A few of these remarkable and grotesque garments are worth brief descriptions, as showing the contrast with the plain apparel of men and women in our own practical age.

During the fifteenth century many remarkable modifications in the sleeves of garments were worn at various times. In Germany, for example, one costume of a gentleman was made with flowing sleeves reaching almost to the ground, the right and left sleeves being of different design. Thus the left sleeve might be made as a long bag, perhaps two feet in diameter, of practically the same width at all points. The right sleeve, on the other hand, might be made funnel shaped, with a gaping wristband reaching to the ground when the hand was held at the waist. The waist of this garment was usually belted about the loins, the skirts reaching below the knees and slashed up the side to allow freedom in walking—and incidentally to exhibit the gaudy, close-fitting trunks beneath.

A century later the Germans were, perhaps, leaders in the very remarkable custom of dressing the two sides of the body in garments of absolutely different designs and colors. A gallant viewed from the left side, for example, might seem to be attired in a coat of green and white, with immense puffs at the shoulders tapering to a close-fitting, forearm sleeve. His hips might be surrounded with red and white puffs striped lengthwise, with the same colors formed into close-fitting hose reaching to the foot. Viewed from the opposite side there was a complete transformation in his appearance. His right sleeve might be red and blue, small and close-fitting above the elbow, but swelling into gorgeous puffs of immense size about the wrist. The puffings about the hips might be omitted; while in place of the plain striped hose of the left leg, the right one would be puffed and slashed, and made into folds of half a dozen colors down to the knee, and perhaps a plain simple color from that point to the ankle.

This is but one of the hundreds of remarkable costumes worn at that time, and is drawn from absolutely authentic sources. But every gallant apparently strove to produce some unique form of garment, more outlandish, if possible, than that of his neighbor, and the result was a motley array that beggars description. At the same time the women of the period were frequently costumed in dresses differing very little from some of the patterns of the nineteenth century.

In this same period the "sober Englishman" was far from sober in his attire. He did not perhaps equal the German in the matter of fantastic design, but he was not far behind. He, too, loved flowing sleeves and puffs, and sometimes he wore a hood or cap with a peak behind that trailed to the ground, unless he tucked it into his girdle, or wrapped it about his neck, as he did upon occasion.

His consort, meanwhile, wore garments puffed and sometimes hung about her by means of stays and whalebones that suspended the garments at a considerable distance from the body, and must have given her the appearance of a movable tent. Her headdress was sometimes a yard or more high, with veil and streamers reaching to the ground behind her. Sometimes her hands protruded from the sleeves; or again they might be concealed in long flowing sleeves similar to those of her lord, and reaching to her ankles.

On the whole, however, the women were perhaps less extravagant in their dresses than the men. But both sexes exhausted their ingenuity in devising new and outlandish costumes. Meanwhile the moralists and satirists, ably assisted by the clergy, were waging ceaseless war upon the fashions, although their combined efforts apparently had little effect.

The Oriental custom of wearing wide flowing trousers gathered about the ankles seems never to have been popular, at least for any length of time, among the Western nations. The leg, from knee to ankle, was almost invariably clothed in some kind of tight-fitting hose, no matter what fantastic garments were worn above. Wide trousers, several yards in circumference were worn at times during the fifteenth, sixteenth, and seventeenth centuries, but these were gathered at the knee or just below it. In those centuries, also, the thighs were frequently puffed and padded, and the hips were sometimes surrounded with puffs of enormous dimensions.

The Italians were the last to give up long monk-like garments for hose and trousers. Possibly their proximity to the Orient had something to do with this. But, whatever the cause, long robes resembling skirts were worn by Italian gentlemen long after such garments had been abandoned by other European countries. Even to-day long sleeveless cloaks reaching to the ground are worn by many men in Italy, possibly a survival of the old medieval robe.

Curiously enough, some of the early Portuguese fashions more nearly resembled modern forms of male attire than those of any other nation for three centuries following. In the sixteenth century a costume was sometimes worn very much like that of a modern Mexican or Spaniard. This consisted of a broad-brimmed "cowboy" hat, a coat not unlike the modern frock coat except that it was belted, and trousers reaching to the ankle, rather wide but not gathered in at the bottom. Ruffs or lace were worn at the throat and about the wrists in place of linen collar and cuff, and a "Spanish cloak" in place of an overcoat; but otherwise the sixteenth-century Portuguese gallant would have passed muster as a twentieth-century Spaniard.

The Church, which for many centuries wasted much oratory in preaching against extravagance in dress, did not set a very good example in practice. Many of the lower orders of monks, to be sure, dressed in the severest manner possible, but the superior dignitaries clung to gaudy colors and rich display—as they do still. Shortly after the fall of the Western Empire in 476 A.D. the dress, even of a bishop, was a plain, toga-like garment. But colors and decorations soon crept in, and by the tenth century the flashy robes even of an under-bishop rivaled the most gorgeous modern woman's gown.

FASHION VERSUS COMFORT

Possibly the most remarkable and grotesque fashion in female attire, if the subject admits of superlatives in contrasting different periods, was that of the great hoop-skirt of the eighteenth century. The size of some of these skirts surpasses belief, frequently being so wide that damsels found it difficult to pass through some of the narrow streets of London and Paris. What must have happened when two determined hoop-wearers met in a narrow alley can only be conjectured. There may have been some unwritten "rules of the road" to cover such emergencies.

By way of contrast to the wide, bell-shaped lower garment, a close-fitting bodice was worn, frequently sleeveless, and the hair was dressed low. The general appearance presented by the tiny body protruding above the dome-like structure of the hoop-skirt must have been "like the knob on a bell-jar."

But the mere bodily discomfort of wearers and of others were not the only evil effects of these great hoop-skirts. At times they threatened the social equilibrium of nations, as happened in the case of France in 1728, "when hoop-skirts were the subject of serious consideration with the minister, Cardinal Fleury. When the queen attended the opera she was accustomed to sit between the two princesses, and the result was that her Majesty was completely hidden by the hoops of her companions. In French eyes this amounted to a positive scandal, but it was impossible that the queen should go to the opera unattended, and it was equally out of the question for the princesses to go without their hoops. What was to be done? Only one thing: a space must be cleared about the queen. Orders were accordingly given that a *fauteuil* should be left vacant either side of the queen. This instruction was carried out, but the princesses had no intention of being eclipsed in their turn, and demanded that a similar space should be left between them and the duchesses.

"It is related that a French lady, who went to confession in a hoop, was quite unable to squeeze herself through the door of the confessional and approach the grating. After repeated struggles she was obliged to give up the attempt, and return home with her load of unconfessed faults."

During all the centuries of caprice and change in fashion, only one Western nation has remained practically unchanged, even until the present time, in the matter of dress. This nation is Scotland. All through the ages the kilt has remained the characteristic dress of the Scot, and while there have been minor modifications from time to time, there has been little tendency to depart from the original garment worn at the earliest historical periods. The Scotch regiments that marched against the Boers a few years ago, only differed in general appearance from the clansmen who fought under Bruce and Wallace in the weapons they carried. And these same soldiers exemplified the tenacity of purpose that has kept the kilt unchanged for centuries, when they declined to discard them for less conspicuous garments, in the face of the terrible slaughter brought about by the conspicuousness of their attire.

THE RETURN TO THE COMMON-SENSE AGE IN CLOTHING

What the immediate cause may have been that led up to the abandonment of the extravagant and grotesque costumes of the eighteenth century and the gradual adoption of men's clothing which reverted almost to primitive simplicity, is difficult to say. It is probable that no single cause was responsible for this change, any more than for the other revolutionary changes that make the nineteenth century a distinctive one in the history of the world.

It is difficult to show that the enormous strides made in scientific discovery had any direct influence upon fashions in clothing; and yet it is probable that indirectly, at least, this influence was enormous. The discoveries in science explained in a common-sense way many hitherto mysterious phenomena and tended paradoxically to simplify, while extending, all fields of thought. And since this general tendency was so universal, it may be that it affected people's taste in clothing as well as their views in many other fields of thought.

In recent years the great revolution, not only in fashions of clothing, but also in the methods of making garments, has been influenced enormously by the sewing-machine. But sewing-machines played no part in the beginning of this revolution, as they were not then invented. It must have been some other influence, therefore, which gradually and unconsciously made itself felt in the closing years of the eighteenth century, that resulted finally in the complete revolution during the last half of the nineteenth century.

The age of modern clothing may be said to date from the going-out of powdered wigs, startling colors, fine fabrics in men's coats and waistcoats, and the abandonment of knee-breeches. As regards these last, it is an open question whether the modern garment that has replaced them is an improvement from the common-sense point of view, and this is perhaps emphasized by the fact that in recent years there has been a tendency both in civilians and in soldiers to return to the shorter type of garment.

The transition period of garment-wearing began early in the nineteenth century when waistcoats were shortened, lace and ruffs abandoned, and the knickerbocker, which until that time had extended only to the knee or just below it, was lengthened so as to reach to the middle of the calf. This again was lengthened to the ankle, and was finally fastened there, not as with the Oriental fashion of gathering about the foot, but with a strap buckled underneath it.

At the present time the summer garments worn by men and women, represent, perhaps, the most practical and simple costume ever worn except by the most primitive races. Shirt-waists for women and plain skirts, negligée shirts for men, with hats of a relatively simple type for both sexes, and shoes with most practical types of heels, combine to form wearing-apparel perhaps as nearly ideal as is possible under modern conditions.

THE WHOLESALE MANUFACTURE OF CLOTHING

The manufacture of ready-made clothing had the most revolutionary effect upon all forms of clothing for both sexes. In this revolution, the sewing-machine has, of course, played the all important part, and yet the revolution had begun several years before the sewing-machine had been invented. As the United States was responsible for the development of this machine so also this country seems to have taken the initiative in the manufacture of ready-made clothing and has held the position preeminently ever since.

Just when the manufacture of clothing began as a separate industry cannot be determined accurately, but it seems certain that the first steps in this direction were taken during the first or second decade of the nineteenth century. At this time certain New York manufacturers began putting out ready-made garments, among these being George Opdyke, who was once mayor of New York. About 1831, he began manufacturing clothing in an establishment in Hudson Street, which he conducted on a small retail scale. Other manufacturers soon fell into line and by 1835 medium-grade clothing for men was being manufactured wholesale, although in limited quantities. Some time before this it had been customary for the stores in seaport towns to manufacture and keep in stock the coarse clothing outfits used by sailors, but such clothing was made on a relatively small scale and consisted only of the most simple type of garments.

From this small beginning in clothing manufacture in the third decade of a century, the industry gradually increased, until by the time of the invention of the practical sewing-machine in 1846, it had become quite an important industry. But the great impetus to this industry was given in that year by the introduction of machines which were capable of performing the work of three or four seamstresses. From that time until the outbreak of the Civil War there was a steady increase in the production of clothing, more particularly that of cheaper grades.

The greatest impetus to wholesale production was that given by the Civil War itself, when the government was forced suddenly to provide clothing for hundreds of thousands of men. To meet this demand factories were established, improved machinery and methods introduced, and as the demand lasted for a period of about four years, the industry became an established one, and ready-made clothing a staple product.

Since the Civil War, however, the methods prevailing in the manufacture of clothing have greatly changed. Before that time it was mainly a household industry, and there were comparatively few manufacturers having factories of their own. Most ready-made clothing was made by journeyman tailors, particularly after the introduction of the sewing-machine. During the spring and fall seasons these men worked for custom tailors, returning to the shops of the manufacturers for work between seasons. Most of these tailors at that time were English, Scotch, or American, and all were skilled workmen capable of turning out an entire garment. A little later the Irish came conspicuously into the trade, and still later the Germans entered the field in great numbers, introducing a system of division of labor in garment-making, that laid the foundation for modern methods as now practised. These Germans worked in families, and the garments were made in their homes, the father doing the machine work, while the mother and children assisted in basting, making buttonholes, sewing on buttons, and finishing.

THE "TASK SYSTEM" INTRODUCED

This system continued until about the beginning of the last quarter of the century, when, following the great influx of Russian Jews, the obnoxious "task system" was introduced. By this system the work was done by "teams" consisting of three men—an operator, a baster, and a finisher. Besides this team there was usually a presser, and one or more girls for sewing on buttons and making buttonholes.

Each member of the team made his particular part of the coat, and the amount of work possible to be produced with such a combination was a great increase over the older system. As a rule, the contractor was a member of the team, at least until the business had developed until he could run three or more teams in his shop, when he became a bushelman, or overseer. His workmen were paid by the week, working a stipulated number of hours each day, and while there was no contract as to the amount of work which they should produce, there was a tacit understanding as to the number of coats or suits that should be completed each week.

This overseer obtained his goods from the manufacturer, and was held responsible for them, and during times of prosperity both he and his workmen received reasonable remuneration. But when times were hard, and labor correspondingly plentiful, the manufacturer frequently cut the price paid the contractor, compelling him to work for less money or remain idle. The overseer would then in turn state the condition of things to his employees, offering them their choice of working for reduced wages, or of increasing the weekly output by working more hours. Almost invariably the employees chose the alternative of longer hours, with the result that while receiving only the same pay as before, they sometimes produced more than double the amount as when working under the older system.

INCREASING DIVISION OF LABOR

The task system was the beginning of specialization in the clothing industry. By that system five persons worked on a single garment, each performing a specified task and completing it considerably more quickly than at the rate of five to one, as against each person finishing an entire garment. But this system was so obnoxious on account of the many hardships imposed upon the workmen by the manufacturers and sub-contractors, that very soon what is known as the "Boston" system or "factory" system became popular.

In this, the specialization in the work was still further extended until in some factories as many as one hundred workmen, each performing different tasks, were required to make an ordinary coat. By this system little skill was required on the part of any of the workmen except the finishers, and even these were relatively unskilled as compared with the old type of journeyman tailors. Any workman, even of mediocre intelligence, could quickly learn to sew together a few pieces of cloth cut into definite shapes in a certain manner. He not only learned to put them together but to do this particular part of the work much more rapidly than even a very skilful tailor. The result was that the manufacturer, by employing a few skilled finishers and a great number of unskilled workmen performing a single task, could produce in the aggregate a far greater number of garments made equally well in a given time than by the older system.

Even the factories themselves became specialized, certain factories only making coats, others vests, and still others trousers, only a comparatively few attempting to turn out the entire garment. The wholesale dealer who had contracted for a thousand suits of a certain pattern might receive the coats from a factory located in New York City, the vests from a factory in Jersey City, and the trousers perhaps from Philadelphia.

As a rule these factories were independent establishments knowing nothing of the others, each finishing its own particular garments, which were assembled in the establishment of the wholesaler.

STEAM AND ELECTRICITY IN FACTORIES

For many years after ready-made clothing had become a standard factory-product, about the only mechanical aids to the garment-maker were the sewing-machines. Garments were still cut out by the time-honored shears, pressed with old-fashioned flat-irons, and buttonholes worked and buttons sewed on by hand. About 1870, however, the first mechanical substitute for shears came into use. This was in the form of a machine carrying great knife-blades which worked like saws back and forth, through several thicknesses of clothing. These first straight-bladed cutting-machines were quickly supplanted by machines made with circular disk blades, cutting like buzz-saws, using a knife-edge instead of teeth. With these machines almost any number of thicknesses of cloth might be cut at one time, a hundred pieces being turned out as quickly as a single one could be cut by the old hand-method. If a hundred sleeve-pieces of the same size were to be cut, a hundred pieces of cloth were clamped together, the pattern laid out, and the cloth sent to the cutting-knife. A few rapid passages of the blade, and a hundred sleeve-pieces were ready for the sewing-machines. A single workman controlled the machine that cut from fifty to a hundred times faster than the hand-workman, and at the end of the day he had neither aching fingers, arms, nor shoulders, as in the case of a hand-workman.

Another machine that came quickly into use was the buttonhole cutter. This could turn out the work not at quite the same wholesale rates as the cutting-machine, but at the same time it was much faster than any hand-methods. By the older method buttonholes could be cut in a hundred coats in about three hours and a half; but by the new machine this time was reduced to less than twenty minutes.

One of the slower processes in garment-making is that of sponging and shrinking the cloth. For centuries this has been done by the use of the sponge and flat-iron, the time required by an average workman to shrink a coat being about fifteen minutes. At the present time the shrinking is done by the steam-sponging-machine with which an average workman can shrink a coat in something less than two minutes, with less exertion than that expended in the older process.

A somewhat similar device in the form of gas or electric flat-irons is now replacing the old-fashioned iron heated on the familiar octagonal soft-coal stove. The first step in this direction was the flat-iron heated by means of charcoal—a miniature stove in itself. But such flat-irons were not entirely satisfactory, from the facts that the temperature could not be controlled and that they required close watching. But by using gas or electricity in place of charcoal, an iron was invented that would remain at any desired temperature for an indefinite length of time. From a hygienic standpoint this was one of the most beneficial innovations in the workshops. By the older method the air of the shop was vitiated in the winter time by stoves, while in the summer time the same shops were heated to suffocation. With the gas or electric flat-iron only the heat of the iron itself is given off, and with the electric iron, at least, there was no vitiation of the atmosphere. Both these types of irons are great time-savers, from the fact that there is no stopping to test or change irons. The danger of having the iron too hot or too cold is also avoided.

Of course the great time-saver in the factory is the sewing-machine in its various forms. Aside from the cutting and pressing almost the entire process of manufacture is now performed on special sewing-machines, practically no handwork being done on the cheaper garments. Many of these are still run by hand, but steam and electricity, particularly the latter, are rapidly replacing foot-power, as referred to more extensively in the chapter on the sewing-machine. Among the remarkable adaptations of the sewing-machine, are the ones for working buttonholes and sewing on buttons. The first of these outstrips the seamstress some thirty to one, while buttons can be sewed on something like eight times faster than by hand.

While the proportion of ready-to-wear clothing manufactured is much larger for men's clothes than for women's, the latter is a growing industry increasing steadily in importance. The first manufactures of this kind, in the form of cloaks and outer garments, were made in the early sixties, and cloak manufacture was about the only one engaged in extensively until about a quarter of a century ago. Since that time complete outfits of ready-made garments of every description have been in the market.

The system of manufacture, however, has not been developed on the enormous scale as that of male clothing. Many extensive shirt-waist factories and general garment factories are in existence, and are increasing constantly in number, but the "task" and "sweatshop" systems have never been developed extensively in this industry.

IV

THE SEWING-MACHINE

ABOUT half a century ago, when the sewing-machine was still in the early stages of development, an eminent lawyer, pleading the cause of its inventor, told eloquently of the wonders it had already accomplished. "The sewing-machine," he said, "has opened the doors of workshops, tainted by the pale victims of the hand-needle, whose long and confining imprisonment to its service was preying upon their health, and rapidly fitting them for the premature grave to which it had already hurried millions of their sex; and the continued tax upon whose vision, in scanning minutely the close relation between the needle-point and the last stitch in the process of sewing, had already so affected their eyesight as to threaten them with a speedy discharge from employment for the want of ability to see.

"The sewing-machine has called them out of such employment, and tenders them a more healthy occupation and higher wages for less time. It has called multitudes out of the non-productive, time-wasting, and health-destroying service of hand-needle sewing, where much labor was bestowed and much time spent to produce small results—and as a consequence all other expenses of the business in which it was done were accumulated to such an extent as not to afford liberal pay to the laborer, and has introduced them into other occupations more favorable to their health, and in which larger results are produced by them in less time and by less labor; and the result is, that higher wages can, in consequence, be afforded and is tendered to them.

"The sewing-machine has entered the dwellings of poverty, met there the widowed mother, upon whom hand-needle service, in her efforts to feed her offspring, was already inflicting the penalty of corroding and emaciating disease, and taking her by the hand, extricating her from the grasp of exacting necessity which tied her to the needle, and led her out, and pointed her to a way of health and plenty."

If a man could thus carry conviction by the weight of overwhelming truth at that time, what might be said now, in the light of intervening years of progress, when the social fabric of communities—possibly nations—has been changed by this device.

In the opening years of the nineteenth century, when the cotton-gin, spinning-frame, and power-loom had made it possible to produce more thread and cloth than could be utilized by seamstresses sewing by hand, a great want was felt of some mechanical device which would shorten the labor of putting the cloth together, just as other machines had shortened the process of making it. But for many years the problem remained unsolved, despite the fact that hundreds of inventors were attempting its solution.

The difficulty lay in the fact that most inventors attempted to make the machines do the work of sewing along somewhat the same lines as it was done by hand—that is, through-and-through sewing, with a needle having an eye at the opposite end from the point. Until this idea was abandoned there was little hope of producing a practical mechanical substitute for hand-sewing. For the operation of sewing as performed by the seamstress is far too complicated to be performed by machinery, and the kind of stitch employed is not practical for mechanical sewing-machines. But, as we now know, neither the principle of sewing employed by the seamstress, nor the kind of stitch she uses, are necessary, and it was not until this idea was grasped by inventors—the idea that new principles might be employed—that the sewing-machine became a practical possibility.

The first attempts tending in the right direction seem to have been taken in England by Charles F. Weisenthal, in 1755, who patented a machine for sewing hand-embroidery. This machine used a double-pointed needle with an eye located in the center, but no attempts were made to adopt it for sewing cloth. Various machines, employing something the same principle, some of them using rows of needles in place of a single one, followed this first, a few of them fairly successful for embroidery work. Most of these machines were designed in England, American inventors not yet having entered the field.

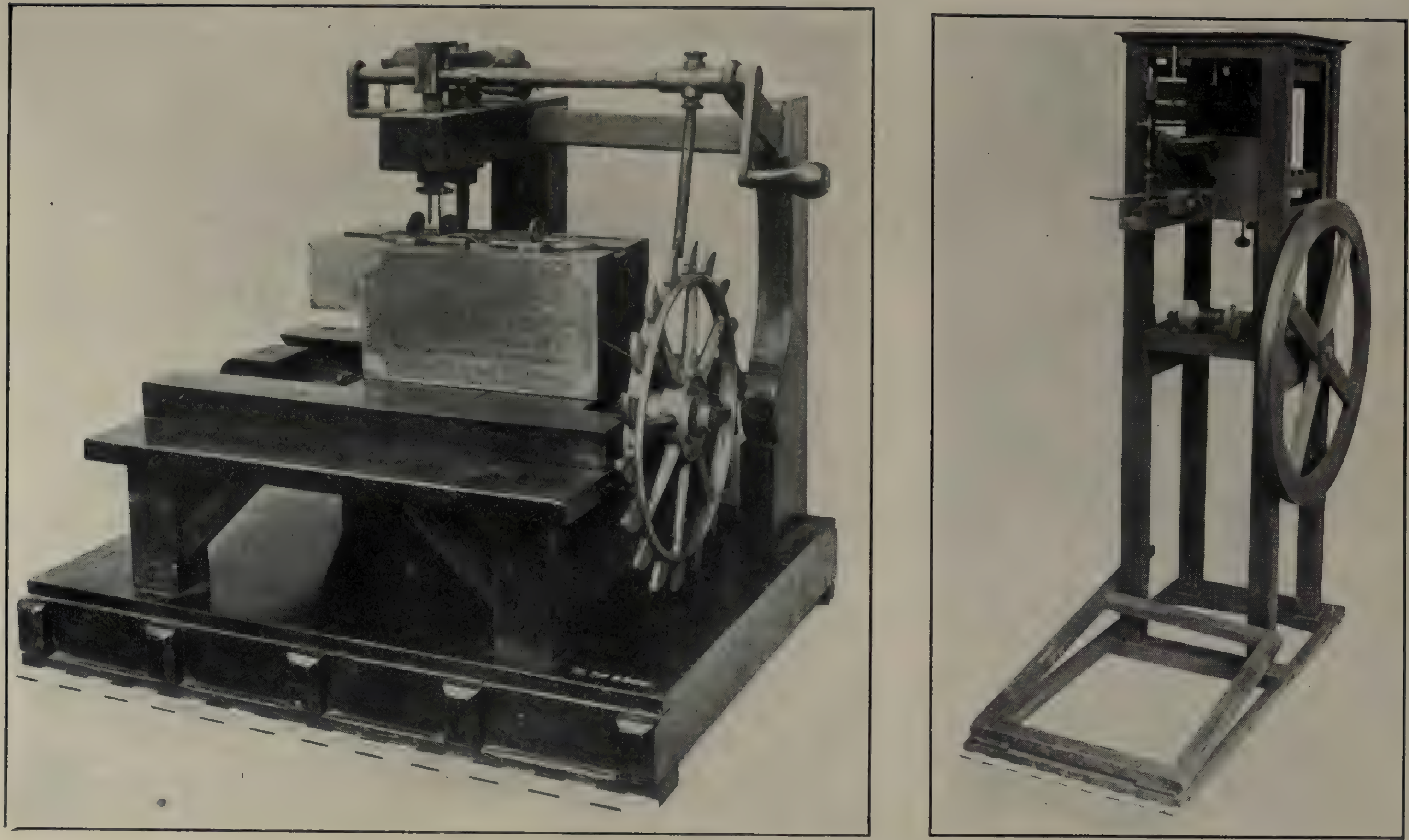
As early as 1790 an Englishman named Thomas Saint conceived an idea which, had it been carried out, would certainly have led to the perfecting of a practical machine many years earlier than Howe's culminating achievement. But although Saint filed his drawings in the English Patent Office, it is not recorded that the inventor ever believed sufficiently in his conception to construct a machine along the lines of his specifications. Both the man and his designs were lost sight of until many years after the perfection of the practical sewing-machine.

THE FIRST PRACTICAL SEWING-MACHINE

It was not until 1830 that a practical sewing-machine for sewing cloth was made. Then a Frenchman, Barthélemy Thimonnier, devised such a machine and took out patents. Improvements quickly followed this first attempt, and by 1841 eighty of these machines, clumsy affairs made mostly of wood, were being used in a Paris shop for making army clothing.

These machines, like the one designed by Saint, made use of the vertical needle descending from the end of an arm, and piercing the cloth held upon a flat table beneath. The needle was depressed by a treadle and cord, and raised by a spring. The needle itself was barbed like a crochet-hook, and worked by plunging through the goods, catching a lower thread from a thread carrier and looper beneath, bringing up a loop which it laid upon the upper surface of the cloth. A second descent brought up another loop, and enchained it with the first one, thus forming a chain-stitch with the loops above.

That this machine was practical is shown by the



EARLY TYPES OF SEWING MACHINES.

The left-hand figure shows a model of a crude sewing machine invented by Thomas Saint in England in 1790. The figure on the right shows a Thimonnier machine, the original of which, made in France in the year 1830, was probably the first practical sewing-machine ever constructed. Both these models are now in the Victoria and Albert Museum, London.

fact that eighty of them were in use for making clothing in 1841. In that year, however, a mob attacked the shop containing the machines, and destroyed them. The reason for this act was the usual one common among European workmen at that period—the fear that their employment would be taken away by these labor-saving devices.

For a few years that attack retarded the progress of inventors, but about 1847 Thimonnier appeared in the field with machines still further improved, capable of making two hundred stitches a minute, and sewing any material from thin cloth to thick leather. Once more the fears of the seamstress were aroused, and in 1848 a mob again attacked the shop of the inventor, and not only destroyed his machines but attempted to kill him.

From the effects of this attack the inventor was never able to rally, either in spirit or financially. He had been struggling for years in poverty, and it was only through the generosity of admiring friends that he had been able to set up his first shop, and later his second one. When this last was destroyed no further aid was forthcoming, and the man whose machine came so near to revolutionizing the industrial world, died a little later in poverty and actual want.

AMERICAN INVENTORS ENTER THE FIELD

About this time American inventors came conspicuously into the field. John J. Greenough, in 1842, had patented a machine using a double-pointed needle and short thread. It was designed primarily for sewing leather, and was made so that an awl pierced a hole for the passage of the needle. The material to be sewed was held in clamps, and fixed in a rack which could be moved both ways, alternately, to produce a back stitch, or allowed to continue in one direction for making a shoemaker's stitch. The needle was passed through the leather by means of pincers, the thread being drawn out by weights. In actual practice this machine did not work well, but was noteworthy because some of the principles involved were utilized later in the practical sewing-machines.

But no machine sewing with a chain-stitch, like that of Thimonnier, could be entirely satisfactory. One great step, that of placing the eye of the needle at the point, had been taken, but another was necessary, and this first one was not fully appreciated until the invention of the lock-stitch—the stitch made by passing another thread through the loop formed by an eye-pointed needle, the second thread interlocking with the first in the fabric.

This idea seems to have been first conceived by Walter Hunt of New York, in 1834, who constructed a machine using a curved needle having an eye near the point, driven by a vibrating arm. This needle formed a loop of thread under the cloth, through which a thread was carried by an oscillating shuttle. In this way a lock-stitch was made in very much the same manner as in the modern sewing-machine. This machine, although it was really a forerunner of all practical sewing-machines, was thought so little of, even by its inventor, that it was sold for a trifle to a blacksmith named Arrowsmith. Twenty years later, when the possibilities of the sewing-machine had been demonstrated by Elias Howe, Hunt attempted to assert his prior claim to a patent, but this was denied him on the ground of abandonment.

The field of successful invention had now been opened up in America, and thenceforth practically every important improvement was made in the United States. Many inventors had entered the field, but as yet no one had solved the problem satisfactorily.

THE COMING OF HOWE

"But 1845 was on its way," says Gifford, "and bearing with it a messenger of reform—a young man, an American, poor in money but rich in genius, feeble in influence but strong in mind. Cambridgeport, Massachusetts, was to have the honor of his birthplace, and Nature was preparing him for the work which all others had failed to accomplish. She well knew how to do it. She always knows from what ranks to pick her candidates for great things, and she equips them with proper habiliments for their mission. Hopes and anticipations of his success were not to be encumbered by present luxury and ease; he was not to be attracted to, or entertained by, present pleasures; he was to be trained for taking mental leave of present surrounding objects and things, and sending his thoughts and projecting his researches far in advance of the front ranks of his contemporaries. He was to be endowed with remarkable energy, patience, self-reliance, and penetrating mental vision; and these, under the command of superior judgment, led by fearless ambition, were to be pressed into action by present obscurity and neglect; the contrast between the shades of surrounding poverty and resplendent glory in anticipation of attaining what the best efforts of the ablest minds had failed to do, was to constantly bear upon him, and resist the discouraging effects of successive disappointments. This was Elias Howe, Jr., and he was destined to become, as results show he was, one of the greatest inventors of his age, and, through his invention, one of the greatest benefactors of his race.

"He espoused the great and benevolent cause of putting the world in possession of the art of machine-sewing. He was protected from the discouraging effects of the results of others' efforts by being kept in ignorance of them. He was not to know of the abortions of Greenough, Corlis, and Thimonnier, or of the experiments of Hunt. He struck out a new course for research and experiment, gradually overcame the difficulties which presented themselves and at length succeeded in exhibiting the trophy of complete success. And what was it? What did it consist of? What rendered it a thing of so much power and value? The answer is, that it consisted of bringing together for the first time, and organizing in harmonious and effective relations, the great, essential features indispensable to a practical sewing-machine."

This invention of Howe's combined the eye-pointed needle with the shuttle for forming the stitch and the intermittent feed for carrying the material forward as each stitch was formed. The device for thus feeding the cloth consisted of a thin strip of metal provided with a row of pins on one edge, but the cloth to be sewed was not held in the horizontal position as at present but carried in a vertical position. Neither did the cloth run through continuously, but was fed the length of a plate, and had to be rehung as often as the length of the plate had been traversed. The curved eye-pointed needle used was attached on the end of a vibrating lever, which also carried the upper thread. The lower thread was passed between the needle and the upper thread by means of a shuttle working on the same principle as the modern one.

Foreseeing the possibilities of his invention, Howe exhausted his scanty means in taking out a patent, and constructing a machine which he deposited as a model in the United States Patent Office. He then cast about to find capital for pushing his enterprise, but failing in this he was compelled to dispose of his patent for a sufficient sum to carry him to England, where a corset-manufacturer had secured his rights to the patent on the payment of the equivalent of about one thousand dollars.

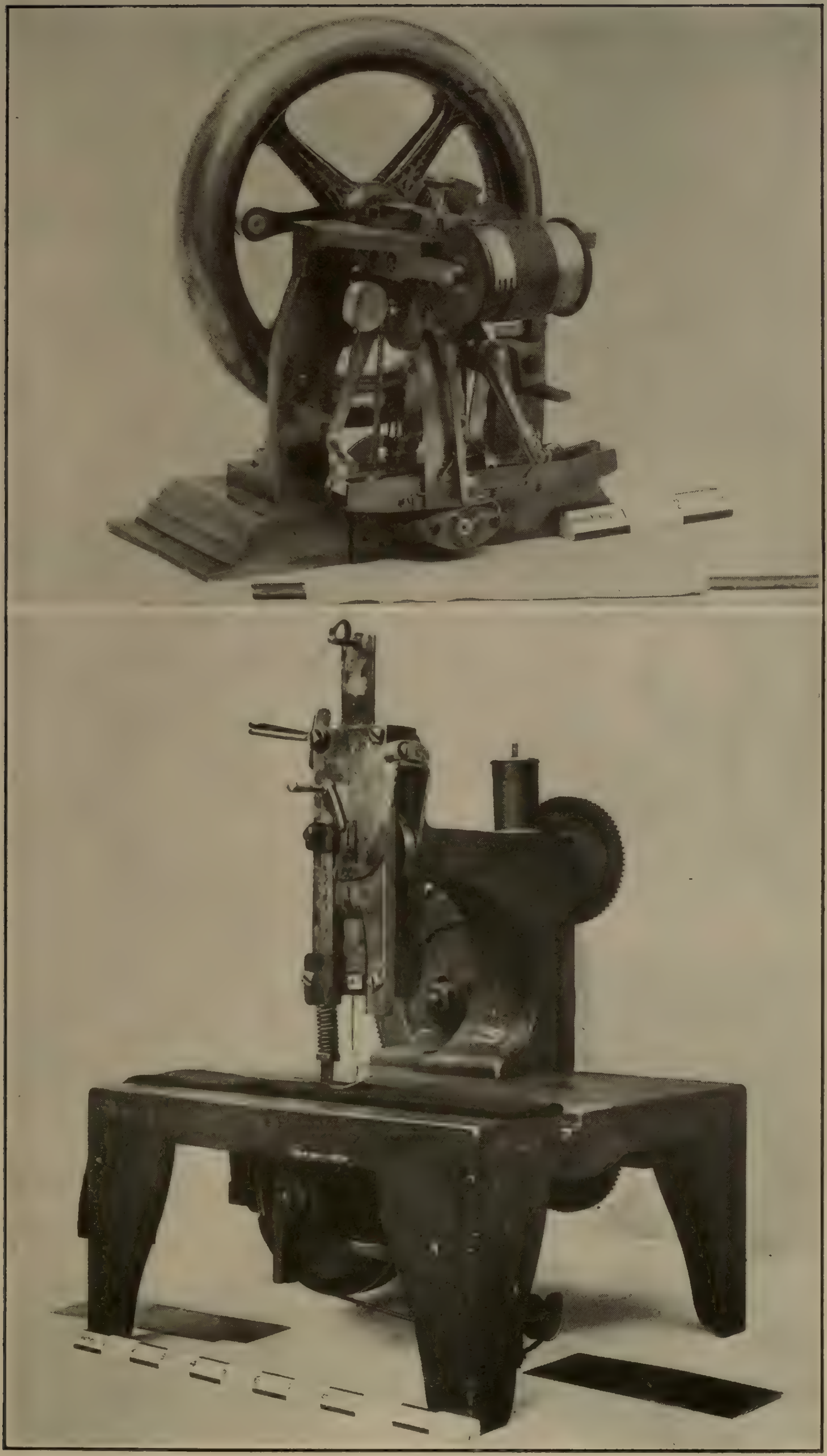
While perfecting this machine and adapting it to corset-making, Howe engaged to work for this manufacturer at a nominal salary. For some reason that is not apparent he was unable to satisfy the wishes of his employer, and in a few months retraced his steps to the United States, poorer, if possible, than ever before. Not disheartened, however, he succeeded in securing a half interest that had been conveyed to his father before his departure for England, and at once began suits in the Boston and New York courts against manufacturers who were making machines infringing on his patents.

The legal controversy was long and bitterly contested, but in the end Howe succeeded in establishing his claims. By this time, however, sewing-machines had become necessities, and the inventor began reaping his reward by compelling manufacturers using his patent to pay a bounty of twenty-five dollars for each machine manufactured, or to cease manufacturing.

SUNDRY IMPROVEMENTS

Such machines were crude affairs, with vertical table and intermittent feed; but in 1849, John Bachelder made the next fundamental and important step of combining the horizontal table and continuous feed device. The feed consisted of an endless band of leather set with small steel points. These points projected up through the horizontal table and penetrated the material to be sewed, carrying it by an intermittent motion to and beyond the needle.

This was a great improvement over Howe's device, but was entirely superseded by the invention of Allen B. Wilson, two years later. This was what is known as the "four-motion feed," which is noted for its simplicity of action and admirable adaptability to the purpose for which it was designed, and is still a popular one. It consists of "a serrated plate, which rises



EARLY TYPES OF SEWING-MACHINES

The upper picture shows an exact copy of the first successful lock-stitch sewing-machine made by Elias Howe, in 1845. The cloth to be sewn was held vertically pinned to a thin strip of metal made for the purpose. The lower shows one of the first Singer sewing-machines—the type of all modern machines—made in 1854, and still in working order.

through a groove in the table on which the material is fed, and by a horizontal motion carries the material forward the length of the stitch, when it drops below the surface of the table and is carried back to its former position at the end of the groove, thus describing a motion following the four sides of a parallelogram. The cloth is held in place by means of a presser-foot descending from the head of the overhanging arm. The motion which carries the cloth forward is so regulated as to take place while the needle is above the surface, and by limiting the extent of this motion the stitch is easily adjusted."

But the ingenuity of Wilson was not exhausted by this single great improvement in the sewing-machine. The following year he invented a new device for executing the lock-stitch, which consisted of a rotating hook used in place of a shuttle for interlocking the upper thread with the lower. This device, with some modifications and improvements, is still the distinguishable feature of a certain well-known sewing-machine.

About this time a New York mechanic named Isaac M. Singer became interested in sewing-machines, and very soon constructed a machine from a design of his own, which was a great improvement, in many ways, over previous ones. This was the first machine having a rigid, overhanging arm to guide the vertical needle, which is now the popular type of household machine. But besides this novel feature, there was a departure in the feed, using what was called a "wheel-feed."

Since the general style of the original Singer machine serves as a model for most modern sewing-machines, it may be more fully described here. "A straight shaft in the overhanging arm imparted the motion to the needle, and the shuttle was driven in its race below the feed-table by a mechanism deriving its motion from the shaft by means of gearing. The feed consisted of an iron wheel with a corrugated surface, the top of which was slightly elevated above the level surface of the table. By an intermittent motion the feed carried the cloth forward between stitches without injury to the fabric. This device permitted the cloth to be turned in any direction by the operator while sewing, which was impossible with the styles of feed which perforated the goods. The material was held in place by a presser-foot alongside the needle. This presser-foot embraced an important feature possessed by no other sewing-machine up to that time—the yielding spring, which would permit of passage over seams, and adjust itself automatically to any thickness of cloth. In addition to this original lock-stitch machine, Mr. Singer afterwards contrived several inventions which contributed materially toward the improvement of the sewing-machine. He produced a sewing-machine which used the single chain stitch, and also a double chain-stitch machine for ornamental work and embroidery."

THE PERFECTED MACHINE AND ITS CONQUEST

"The sewing-machine had now arrived at a stage when all its essential features had been discovered by inventors and so far perfected as to demonstrate their practicability. It only remained for men of energy and business ability to apply themselves to the work of manufacture and to the development of facilities for marketing their products. Men who early appreciated the importance of the sewing-machine as a factor in the commercial advancement of the world applied themselves with great zeal to the promotion of the industry. Factories were established in Bridgeport, Boston, New York, and other cities for the exclusive manufacture of sewing-machines. Bridgeport has always held a conspicuous place in the industry, and the history of the development and manufacture of the sewing-machine will always be closely associated with that Connecticut city. The importance of New York city as a commercial center was early appreciated by sewing-machine manufacturers, and it was made the principal sales-depot for that industry by establishments located throughout New England. One of the leading concerns then in existence for the manufacture of sewing-machines carried on its operations in New York city.

"In 1855 litigation arose, involving three of the principal sewing-machine companies then in existence. It was claimed by each of the parties concerned that the others were infringing upon certain of their patent rights. Numerous suits were instituted on these patents, and when the contesting parties finally came together in 1856 for trying some of the cases in court, an amicable settlement was agreed upon whereby the parties to the suits were to pool their patents, thus permitting any one of them to use the patents of all the others so far as might be necessary in the construction of their sewing-machines, and to protect the interests of all from infringements by outside parties. These patents and privileges were not confined to the three original parties in the combination, but were available to all manufacturers upon the payment of a fee, which was very small compared with the exorbitant bounty collected by Howe. No restrictions were placed upon manufacturers in regard to the price at which their products were to be sold, and the markets were open to fair competition by all on the merits of the several machines. The combination continued in existence, with Mr. Howe as a member, until the expiration of the extended term of his patent, in 1867, and was then continued by the other members until the expiration of the Bachelder patent in 1877.

"The sewing-machines manufactured prior to the Singer, and many of them long after, used the vibrating arm for imparting motion to the needle. This result was accomplished either by means of the vibratory arm actuating a needle-bar carrying a straight needle, or by means of the vibratory arm and curved needle. It is obvious that sewing-machines constructed on either of these principles could not be enlarged, or decreased, in size without destroying their effectiveness; on the one hand the lengthening of the arm would naturally increase both the power required to operate it, and its liability to spring, and thus affect the proper action of the needle; on the other hand, decreasing the size of the arm would necessarily increase the curve of the needle and contract the space for turning and handling the work. Singer's arrangement of the rigid overhanging arm made it practicable to enlarge the machine to any desired extent, and added great solidity and strength to the machine, thus making it available either for doing the heaviest kinds of work or for sewing the lightest fabrics. The general style of the original Singer machine has been universally copied, and serves as a model for most of the machines now manufactured.

"The work of adapting the sewing-machine to the various kinds of stitching required in the variety of manufacturing and mechanical industries to which it has been applied, was early taken up by Isaac M. Singer, Allen B. Wilson, and others, and has been successfully continued by later inventors. Machines stitching with waxed thread have been perfected for use in the factory manufacture of boots and shoes, as well as in the manufacture of saddlery and harness and various other articles of leather. Heavy-power machines are used in the manufacture of awnings, tents, sails, canvas belts, and articles of a like nature. Specially constructed machines for stitching gloves, and others for sewing the seams of carpets, sewing the ends of filled bags, stitching brooms, embroidering, and doing various other work, are produced by the leading sewing-machine manufacturers. Machines for working button-holes and sewing on buttons have been made very effective in their operation, and produce a quality of work equal to the hand product at a greatly increased rate of speed.

"Inventions covering the sewing-machine and its attachments are numerous, and patents for them are continually being granted. The same is true of the machinery used in producing the various interchangeable parts of the sewing-machine. The American principle of making all parts of the machine interchangeable has been carried to the fullest extent in this industry. Machines for producing the most intricate parts of the sewing-machine are so perfected that they perform their work with remarkable speed and exactness. The special tools required to make the various parts of sewing-machine often require more inventive talent in their construction than the machine manufactured. In the larger factories the experimental department is one of the most important and expensive. Here the inventor has every facility for developing new ideas and putting the results to preliminary tests. When, after a great deal of time and labor has been expended on an invention, and it has reached an apparently perfect condition, it is sent to a factory engaged in the class of work for which it is designed, and is thoroughly tested. If its operation proves satisfactory, a special plant of machinery is installed for the manufacture of the new machine or attachment, so that any number of duplicates can be made. After all this expensive preparation and experiment, the invention may be soon replaced by something better, and abandoned."

V

CLOTHING THE EXTREMITIES

THE custom of wearing some protection for the foot was undoubtedly adopted by primitive man very early in the period of his history. It is probable that this custom did not originate entirely through a desire to find some protection for the soles of his feet against injurious objects, but rather as a protection against cold. It is known that among any race of men which goes barefoot constantly from infancy the cuticle of the sole of the foot becomes so thick and callous as to have almost the consistency of horn, and a power of resistance almost as great as that of the hoofs of animals. Among certain South American Indians, living in the regions of lava beds, this thick callosity of the soles is so developed that they walk with impunity over fields of broken lava-glass.

Certainly in such regions some artificial protection of the foot is needed if it is needed anywhere. And yet these Indians, although familiar with leather, never use it as a protection for their feet. This seems to bear out the theory that primitive man did not begin wearing shoes as a protection against injury, but as a protection against cold. For the natives of all tropical climates are almost invariably barefooted races regardless of the nature of their surroundings.

It is probable, therefore, that the custom of wearing protection for the feet did not begin until primitive man commenced migrating from the tropical regions into colder latitudes. But even in such latitudes, shoes or moccasins would probably have been worn only during the colder months of the year, as in the case of clothing, and discarded during the warmer months. But, as will be remembered by every boy who has had the privilege of going barefoot in the summer time, confining the foot in any kind of protective shoe for several months tends to soften the callous soles, and the resulting tenderness does not disappear for some time after the shoes are discarded. So the primitive men who had protected their feet by rude skin shoes during the several winter months, would find in the spring that their feet had lost much of their tough, resisting power of a few months before.

As regions further and further north were invaded, where the winters were long and the summers comparatively short, the time would come when the shoe-wearing season would be longer than the barefooted season, and the need of some protection to the soles would be felt acutely when the season for discarding foot-wear arrived. The pleasure of escaping from the encumbrance of shoes would be more than offset by the pain from cuts and bruises that would be received when attempting to go barefoot. A natural summer compromise, therefore, would be in the form of a sandal, which would protect the sole and allow freedom to the upper part of the foot.

In this manner, a race of comparatively tender-footed men, wearing shoes or sandals the year round, would be developed; and while we have no means of determining that this was the actual process of the evolution, it is a most natural one. Such, undoubtedly, is the way in which the wearing of clothing the year round came about, and we may judge by analogy that the wearing of clothing for the feet developed in a similar manner.

It is certain that even in the most remote periods of antiquity shoes or sandals of some form were in use by all civilized, or semi-civilized, peoples. In Egypt, where there was no need of protection against the cold, the sandal was the prevailing form of footgear. These sandals were made of straw, reeds, wood, or leather, and of numerous patterns, some of them plain and designed only for protection, while others were of fantastic shapes, made of costly material and richly ornamented. Some of these sandals were held in place by simple toe-straps, into which the foot was thrust, while others were fastened securely about the ankle and across the foot.

A very common and useful type seems to have been a toboggan-shaped sandal which curved up in front of the toes, with the long point extending backward and fastened to the strap about the ankle. Such a sandal protected the toes from injury by stubbing in the same manner as does the modern shoe.

Among the early Hebrews both sandals and low shoes, or buskins, were worn. A shoe that was a sort of compromise between the buskin and a sandal was also used, this shoe having a thick protective sole, and an upper part covering the top of the foot and surrounding the ankle, but leaving the toes exposed. These, like the buskins, were also made in the form of a boot or high shoe which laced in front and surrounded the calf of the leg.

The shoes and the sandals of the Assyrians were of much the same type as those worn by the Hebrews. On the sculptures they are represented as surrounding the foot completely, reaching to the knee and fastening in front with lacing. This type of shoe was also common among the Persians, and sandals of various kinds were also worn; but the lower classes of all these nations undoubtedly wore no shoes at all, or at most rude sandals at certain seasons of the year.

The Greeks, when they protected their feet at all, wore a form of sandal laced about the foot and ankle; and the Romans wore sandals and low shoes, some of them with very thick soles, but having no heels.

The barbarian tribes in northern countries wore moccasins and leggings very similar to those of the American Indians. Certain nations, as the Franks, carried the analogy to the Indian still further in their weapons and in some of their customs. For the Frankish soldier not only carried a tomahawk closely resembling that of the redskin, but was skilled in throwing it. These barbarians also scalped their victims in true Indian fashion.

Among such Oriental nations as the Chinese there has been little change in the kind of foot-wear used for thousands of years. The thick soled, heelless slipper, with the sole beveled at the point, was worn in antiquity just as it is worn to-day.

Exactly when the wearing of heels began cannot be definitely determined. It is known that the ordinary shoe of the Middle Ages was usually heelless, although sometimes of fantastic design. During the time that the wearing of body-armor was at its height—that is, between the twelfth and fifteenth centuries—most fantastic and inconvenient forms of foot-gear was worn at certain periods, but such extravagance in design was usually directed to the toe of the boot rather than to the heel. This was true of the armor itself as well as the shoes ordinarily worn.

Not content with weighting themselves down with encumbering armor for protection, the knights of that day frequently added to the weight of their already cumbersome load by lengthening and broadening the toes of their metal shoes in a most astonishing manner. From the fact that spurs must be worn at the heel, this part of the shoe generally escaped the freaks of fashion, but there seems to have been no limit to the design and modifications of the opposite end of the shoe. Knights on horseback frequently wore iron shoes two feet in length, while the shoes worn while on foot were sometimes of a breadth rivaling that of small snow-shoes, and giving something the same general appearance with the long spur protruding from the rear.

For two centuries at least there has been no essential change in the general design of boots and shoes. The revolutionary changes have been in the methods of manufacture, and these largely in the last half century when handwork has been so completely supplanted by machinery. The story of this development is admirably told by Mr. George C. Houghton from whose account, as published in the U. S. Census Report, we quote at length.

THE RISE OF THE SHOE INDUSTRY

"The history of this branch of manufacturing, as it has progressed from the shoemaker's bench, where shoes were turned out one at a time, to the modern factory with its output of thousands of pairs daily marks, as do few others, the remarkable industrial progress of the present age.

"The introduction of the boot-and-shoe industry in America is almost coincident with the first settlement of New England, for it is a matter of history that in the year 1629 a shoemaker named Thomas Beard, with a supply of hides, arrived on board the *Mayflower*. This pioneer of the American boot and shoe trade was accredited to the governor of the colony, by the company in London, at a salary of £10 per annum and a grant of fifty acres of land, upon which he should settle. Seven years after the arrival of Beard, the city of Lynn saw the inception of the industry which has given it a world-wide fame, for there, in 1636, Philip Kertland, a native of Buckinghamshire, began the manufacture of shoes, and fifteen years later the shoemakers of Lynn were supplying the trade of Boston. As early as 1648, we find tanning and shoemaking mentioned as an industry in the colony of Virginia, special mention being made of the fact that a planter named Matthews employed eight shoemakers upon his own premises. Legal restraint was placed upon the business of the cordwainer in Connecticut, in 1656, and in Rhode Island, in 1706, while in New York the business of tanning and shoemaking is known to have been firmly established previous to the capitulation of the province to the English, in 1664. In 1698 the industry was carried on profitably in Philadelphia, and in 1721 the colonial legislature of Pennsylvania passed an act regulating the materials and the prices of the boot and shoe industry.

"During the Revolution most of the shoes worn by the Continental army, as well as nearly all ready-made shoes sold throughout the colonies, were produced in Massachusetts, and we find it recorded that 'for quality and service they were quite as good as those imported from England.' Immediately after the Revolution, in consequence of large importations, the business languished somewhat. It soon recovered, however, and was pursued with such vigor that in 1795 there were in Lynn two hundred master-workmen and six hundred journeymen, who produced, in the aggregate, three hundred thousand pairs of ladies' shoes. One manufacturer in seven months of the year 1795 made twenty thousand pairs. In 1778 men's shoes were made in Reading, Braintree, and other towns in the Old Colony, for the wholesale trade; they were sold to dealers in Boston, Philadelphia, Savannah, and Charleston, a considerable portion being exported to Cuba and other West India islands.

"About the year 1795 the business was established in Milford and other Worcester County towns, where brogans were made, and sold to the planters in the Southern states for negro wear. The custom at this time was for the manufacturer to make weekly trips to Boston with his horse and wagon, taking his goods in baskets and barrels, and selling them to the wholesale trade.

EARLY METHODS

"Prior to 1815 most of the shoes were hand sewed, a few having been copper nailed; the heavier shoes were welted and the lighter ones turned. This method of manufacture was changed about the year 1815, by the adoption of the wooden shoe-peg, which was invented in 1811 and soon came into general use. Up to this time little or no progress had been made in the methods of manufacture. The shoemaker sat on his bench, and with scarcely any tools other than a hammer, knife, and wooden shoulder-stick, cut, stitched, hammered, and sewed, until the shoe was completed. Previous to the year 1845, which marked the first successful application of machinery to American shoemaking, this industry was in strictest sense a hand process, and the young man who chose it for his vocation was apprenticed for seven years, and in that time was taught every detail of the art. He was instructed in the preparation of the in-sole and out-sole, depending almost entirely upon his eye for the proper proportions; taught to prepare pegs and drive them, for the pegged shoe was the most common type of footwear in the first half of the last century; and familiarized himself with the making of turned and welt shoes, which have always been considered the highest type of shoemaking, and required exceptional skill of the artisan in channeling the in-sole and out-sole by hand, rounding the sole, sewing the welt, and stitching the out-sole. After having served his apprenticeship, it was the custom for the full-fledged shoemaker to start on what was known as 'whipping the cat,' which meant traveling from town to town, living with a family while making a year's supply of shoes for each member, and then moving on to fill engagements previously made.

"The change from which has been evolved our present factory system, began in the latter part of 1700, when a system of sizes had been drafted, and shoemakers more enterprising than their fellows gathered about them groups of workmen, and took upon themselves the dignity of manufacturers. The entire shoe was then made under one roof, and generally from leather that was tanned on the premises; one workman cut the leather; others sewed the uppers, and still others fastened uppers to soles, each workman handling only one part of the process of manufacture. This division of labor was successful from the very start, and soon the method was adopted of sending out the uppers to be sewed by women and children at their homes. Small shops were numerous throughout certain parts of Massachusetts where the shoemaker, with members of his family or sometimes a neighbor, received the uppers and understock from the factories nearby, bottomed the boots and shoes, and returned them to the factories, where they were finished and sent to the market packed in wooden boxes. Thus the industry developed and prospered and was carried on without any further improvement in methods, until the introduction of machinery a little more than a half century ago.

THE APPLICATION OF MACHINERY

"The first machine which proved itself of any practical value was the leather-rolling machine, which came into use about 1845 and with which it was said 'a man could do in a minute what would require half an hour's hard work with a lapstone and hammer.' This was closely followed by the wax-thread sewing-machine, which greatly reduced the time required for sewing together the different parts that formed the upper, and the buffing-machine, for removing the grain from sole leather. Then came a machine which made pegs very cheaply and with great rapidity, and this in turn was followed by a hand-power machine for driving pegs. In 1855 there was introduced the splitting-machine, for reducing sole leather to a uniform thickness. Peg-making and power-making machines were soon perfected and there had appeared a dieing-out machine, which was used cutting soles, taps, and heels by the use of different sized dies. The year 1860 saw the introduction of the McKay sewing-machine, which has perhaps done more to revolutionize the manufacture of shoes than any other single machine. The shoe to be sewed was placed over a horn and the sewing was done from the channel in the out-sole through the sole and in-sole. The machine made a loop-stitch and left a ridge of thread on the inside of the shoe, but it filled the great demand that existed for sewed shoes, and many hundreds of millions of pairs have been made by its use.

"At the time of the introduction of the McKay machine inventors were busy in other directions, and as a result came the introduction of the cable-nailing machine, which was provided with a cable of nails, the head of one being joined to the point of another; these the machine cut into separate nails and drove automatically. At about this time was introduced the screw-machine which formed a screw from brass wire, forcing it into the leather and cutting it off automatically. This was the prototype of the 'rapid standard screw-machine,' which is a comparatively recent invention and is very widely used as a sole-fastener at the present time on the heavier class of boots and shoes. Very soon thereafter the attention of the trade was attracted to the invention of a New York mechanic for the sewing of soles. This device was particularly intended for the making of turn-shoes and afterward became famous as the Goodyear 'turn-shoe machine.' It was many years before this machine became a commercial success, and mention of its progress is made later.

"Closely following the Goodyear invention came the introduction of the first machine used in connection with heeling—a machine which compressed the heel and pricked holes for the nails—and this was soon followed by a machine which automatically drove the nails, the heels having previously been put in place and held by guides on the machine. Other improvements in heeling-machines followed with considerable rapidity, and a machine came into use shortly afterward which not only nailed the heel but was also provided with a hand-trimmer, which the operator swung round the heel immediately after nailing. From these have been evolved the heeling-machines in use at the present time.

"Notable improvements had during this time been made in the Goodyear system, and a machine was made for the sewing of welts which was the foundation of the Goodyear machine now so universally used. This machine sewed from the channel of the in-sole through upper and welt, uniting all three, and was a machine of the chain-stitch type which left the loop on the outside of the welt. This machine was closely followed by the introduction of one which stitched the out-sole, uniting it to the welt by a stitch made from the channel in the out-sole, through out-sole and welt. This machine afterward became famous as the Goodyear 'rapid out-sole lock-stitch machine.' The great demand that existed for shoes of this type made it necessary that accessory machines should be invented, and those which prepared the in-sole, skived the welt, trimmed the in-sole, rounded and channeled the out-sole, as well as a machine which automatically rolled or leveled the shoe, and the stitch-separating machine were soon produced. These formed the Goodyear welt system which has been the subject of constant improvement up to the present time, and is now in use wherever shoes of a high class are made.

"At the time the first standard-screw machine was attracting attention, the heel-trimming and fore-part trimming machines were brought about. This part of the work had previously been done by the hand-workman, using a shave or knife for trimming, and as he was entirely dependent upon the eye for the proper proportions of the finished sole, the work was not often of a very uniform nature. The heel and forepart-trimming machines greatly reduced this part of the labor, and their adoption was very rapid.

"In the early '70's came a change in a department of shoemaking which, prior to that time, had been regarded as a confirmed hand-process. This was the important part of the work known as lasting; and a machine was introduced at that time for doing this work. This machine, as well as those which followed afterward for a period of twenty years, was known as the bed type of machine, in which the shoe-upper was drawn over the last by either friction or pincers, and then tacked by the use of a hand-tool. At a comparatively recent period another machine which revolutionized all previous ideas in lasting was introduced. This machine is generally in use at the present time and is known as the 'consolidated hand-method lasting-machine.' It was fitted with pincers which automatically drew the leather round the last, at the same time driving a tack which held it in place. This machine has been so developed that it is now used for the lasting of shoes of every type, from the lowest and cheapest to the highest grade, and it is a machine that shows wonderful mechanical ingenuity.

"The perfecting of the lasting-machine has been followed recently by the introduction of a machine which performs in a most satisfactory way the difficult process known as 'pulling over,' which consists of accurately centering the shoe-upper on the last and securing it temporarily in position for the work of lasting. The new machine, which is known as the 'hand-method pulling-over machine,' is provided with pincers, which close automatically, gripping the shoe-upper at sides and toe. It is fitted with adjustments by which the operator is enabled to quickly center the shoe-upper on the last, and, on the pressing of a foot-lever, the machine automatically draws the upper closely to the last and secures it in position by tacks, which are also driven by the machine. The introduction of this machine marked a radical change in the one important shoemaking process that had up to this time successfully withstood all attempts at mechanical improvement. At about the time that lasting was first introduced there came the finishing-machines, which were used for finishing heel and fore-part. These machines were fitted with a tool, which was heated by gas and which practically duplicated the labor of the hand-workman in rubbing the edges with a hot tool for the purpose of finishing them. From these early machines have been evolved the edge-cutting machines which are in use at the present time.

"The latest machine to attract the attention of the trade is one which, in the opinion of those well qualified to judge, is destined to revolutionize the making of that class of shoes which has heretofore been made on the McKay sewing-machine. It is known as the 'universal double-clinch machine,' and forms a fastening of wire, which is taken from a coil corrugated in the machine, and driven, one end being clinched back into the leather of the out-sole. It is further provided with an attachment which makes the channel in which the fastening is driven, and afterward closes it automatically. It makes a very comfortable, flexible, and durable shoe, and is being rapidly adopted by manufacturers.

"At the present time the genius of the American inventor has provided for every detail of shoemaking, even the smallest processes being performed by mechanical devices of some kind. This has naturally made the shoemaker of to-day a specialist, who very seldom knows anything of shoemaking apart from the particular process in the performance of which he is an adept, and from which he earns a livelihood. The American shoe of to-day is the standard production of the world. It is in demand wherever shoes are worn, and although the tools which have made its production possible have been perfected in the face of most discouraging conditions and opposition, they are to-day classed among the most ingenious productions of a wonderfully productive epoch.

LASTS AND PATTERNS

"An important feature of the boot-and-shoe industry is the use of lasts and the system of last-measurements adopted by manufacturers. In the early '50's the methods in last- and pattern-making were very crude, although some of the boots and shoes made in those days were very fine in workmanship, and the amount paid to a workman for simply putting on the buttons, which was done by hand, would, at the present time, purchase a good pair of shoes. Lasts were then made only in whole sizes, such a thing as half sizes being unheard of, and were of curious shapes; first, they would have very broad toes, then would go to the other extreme and run out so thin at the end that it was necessary to iron-plate them. There were only two or three styles and widths, and one pattern would fit them all. Many of the women's lasts were made straight. Very little attention was given to the saving of stock in those days, and in the making of patterns one had only to get them large enough. At the present day the saving of stock in the making of patterns is of the greatest importance. The measurements must be absolutely retained. The character and style must be kept up; and the lines, proportions, and graceful curves must receive the most careful attention in all their details, as these are necessary to make up the symmetrical whole. The early method of producing patterns was largely by guess, and some, it is said, still cling to the old way. At one time what was called the English system was considerably used, the method being to take a piece of upper leather, wet and crimp it over the last, and let it dry. This gave the form of the last, and then the pattern was cut from stiff paper, allowing for laps, seams, and folds. This method gave good results, providing that the person using it had good taste in putting style into the pattern. Later came the Radii system, which some are using at the present day. Still later came the Soule method, and a book was published describing that system. This method, which is said to produce very good results, is still being used by many pattern-manufacturers, and also by local shoe-pattern makers in many of the shoe factories of the country. Some of the most enterprising pattern-makers of to-day, however, are using more modern methods. It is conceded that America leads the world in the manufacture of shoes, principally on account of superior style and workmanship; and the American last- and pattern-makers are entitled to a large degree of credit in establishing the character and style of the American shoe.

METHODS OF MANUFACTURE

"The following gives a fair idea of how a pair of shoes is turned out under modern methods in the factory to-day: First, the cutters are given tickets describing the style of shoe required, the thickness of sole, and whatever other details are necessary. From this ticket the vamp-cutter blocks out the vamps and gives them with the ticket to the upper-cutter, who shapes the vamps to the pattern and cuts the tops or quarters which accompany them. The trimming-cutter then gets out the side-linings, stays, facings, or whatever trimmings are needed. The whole is then made into a bundle and sent to the fitting department. Here they are arranged in classes by themselves. Pieces which are too heavy are run through a splitting machine, and the edges are beveled by means of the skiving-machine. Next they are pasted together, care being taken to join them at the marks made for that purpose. After being dried they go into the hands of the machine operators. The different parts go to different machines, each of which is adjusted for its particular work. The completed upper next goes to the sole-leather room, in which department machinery also performs the major part of the work. By the use of the cutting-machine the sides of leather are reduced into strips corresponding to the length of the sole required. These strips are passed through a powerful rolling-machine, which hardens the leather and moves from its surface all irregularities. They are then shaved down to a uniform thickness, also by machinery, and placed under disks which cut them out in proper form. The smaller pieces are died out in the form of lifts, or heel-pieces, which are joined together to the proper thickness and cemented, after which they are put in presses which give them the greatest amount of solidity. The top lift is not added to the heel until after it has been nailed to the shoe. The remaining sole-leather is used for shank pieces, rands, and bottom leveling.

"For the in-sole, a lighter grade of leather is used, which, being cut into strips and rolled, is cut by dies to the correct shape, shaved uniformly, and channeled around the under edge for receiving the upper. The counters are died out and skived by machine, and the welts cut in strips. The uppers and soles are then sent to the bottoming department, where the first operation is that of lasting, the uppers being tacked to the in-sole. From the laster they go to the machine operator, where the upper, sole, and welt are firmly sewed together by the machine. The bottom is filled and leveled off and the steel shank inserted. Next the bottom is coated with cement, and the out-sole pressed on it by a machine. Thence it is sent through the rounding-machine, which trims it and channels the sole for stitching. From there it goes again to the sewing-machine, which stitches through the welt outside of the upper. The next step is that of leveling, then heeling, both of which processes are accomplished by machinery. The heels are nailed on in the rough and afterward trimmed into shape by a machine operating revolving knives; a breasting-machine shaping the front of the heel. Still another machine drives in the brass nails and cuts them off flush with the top pieces. The edging-machine is next used, which trims the edges of both sole and heel. The bottom is then sandpapered, blacked, and burnished by machinery, after which the shoe is cleaned, treed, and packed. The total floor space occupied by the shoe factories of the United States is practically 2,000,000 square feet, or about 550 acres."

GLOVES AND GAUNTLETS

Recent geological discoveries seem to show that rude hand protections in the form of mittens or gloves were worn by the prehistoric cave dwellers. How much before their time this custom had come into use by our remote ancestors there is no means of determining, but it certainly dates back into very remote antiquity. And yet shoes or foot-coverings were probably worn many centuries before coverings for the hands.

If gloves were first used as protection against cold, they would certainly not have been conceived for some time after similar coverings for the feet had become necessary. Primitive man would have found much less difficulty in protecting his hands against the inclemency of the weather than his feet, as it was a comparatively simple matter to wrap his skin cloak about them when not in use, leaving them free for action when necessary. It is probable, therefore, that even the dwellers in cold climates were wearing shoes and leggings long before hand protections of any kind were worn.

Here again, the customs of the American Indians, as in many other instances, throw light upon the subject. All the northern Indians were familiar with well-made moccasins and leggings, although mittens or gloves of any kind were seldom, if ever, worn by them.

On the other hand it may be possible that the wearing of hand protection originated in the warmer climates, not as protection against cold, but as means of defense in fighting. If this were the case it is possible that the wearing of mittens originated before the time of the wearing of shoes. Even at the present time there are certain tribesmen in Africa who use, in place of shields, a form of hand protection made of skins when hunting dangerous animals. The mode of using these protectors is by wrapping the skins of animals around the left hand and arm, leaving the right hand free for using the spear. When attacked by an animal the hunter holds his skin-protected hand before him, allowing the attacking animal to seize it, in so doing exposing itself to the spear-thrust. In this case, of course, several layers of skin are used, wound so as to form a thickness that will resist the teeth of the animal. But a very natural modification of this arrangement would be a form of mitten made of thick hides, thus partly protecting the left hand while leaving the other free for action. A mitten or glove may have been worn at times on the right hand also.

Another possible origin in the use of gloves, other than for protection against cold, may have been for protection of the left hand in archery. Among all nations, even of remote antiquity, some form of protection to the wrist and hand was known, and while this was usually in the form of a wrist-band, rather than a glove or mitten, the exposed position of the fingers and knuckles as thrust forward in archery may have suggested the use of the glove as a means of protection.

But all these are mere surmises as to how the wearing of gloves may have originated in warmer climates. It is certain that in the northern regions gloves and mittens were worn in very remote antiquity. By the dawn of civilization well-made gloves fitted to the hand and fingers in a manner not unlike the modern glove were in use, and from the time required for the evolution of gloves to this stage of perfection, we may gain some conception of the great antiquity of the custom of glove-wearing.

Gloves were conspicuous during the Middle Ages as part of the regalia of kings, princes, and clergy. Among the many beneficial laws made by Charlemagne was one which allowed the clergy unlimited hunting-rights in order that they might kill a sufficient number of deer to provide themselves with skins for their gloves and book-covers. At that time a hidden significance had been given to the custom of glove-wearing, gauntlets playing an important part in some ecclesiastical rites and ceremonies, and certain ceremonies of kings and princes. This led to great extravagance in designs and peculiarities in the patterns of gloves, particularly among the nobility and the upper churchmen. These extravagances became so conspicuous in the fourteenth century when even the lower clergy had been granted the privilege of wearing gloves, that sumptuary restrictions against any but the plainer types were imposed by the upper churchmen.

The custom of hawking, which became popular as early as the fourth century, is also responsible for the custom of wearing gauntlet gloves in certain countries. As the hawks were perched on the hand of the hunter, some protection to the hand and wrist was necessary against the sharp talons of the birds. Gauntlet gloves, therefore, came into use, the custom of wearing them while hunting extending itself eventually to other occasions.

Although it is undoubtedly true that gloves were worn by women for protection quite as early as by men, they did not form part of the dress of ladies until comparatively recent times. In England they were worn in the fourteenth century, and by the sixteenth century they were made with elaborate embroidery and set with costly gems. After this period, however, plainer gloves were introduced, made in practically the same manner as the ordinary glove of to-day; and while the fashions have changed slightly from time to time during the three intervening centuries, the gloves of to-day are practically identical with the gloves worn in the time of Queen Elizabeth.

THE MANUFACTURE OF GLOVES

As early as the middle of the twelfth century glove-making had become of such importance that societies of handicraftsmen known as "glovers" had been formed in several European countries, France and Scotland being the first to organize such societies. These societies had a decidedly beneficial effect upon both the trade in gloves and in the products themselves, as they controlled the material for making the gloves and prevented dishonest workmanship. By the fifteenth century these glovers' societies had secured many favorable legislative acts, and in the seventeenth century a society of glovers was organized in London which soon made that city the great center of glove manufacture, a position that it has held ever since.

The industry flourished in Ireland also, and the "Limerick glove" became famous for its exquisite texture and delicate workmanship. These gloves were made from the skins of very young calves, kids, and lambs, tanned and prepared in a special manner. Some of them were so delicate that "one might be placed in a walnut shell." For many years these gloves were worn extensively, but were eventually supplanted in popular favor by the French kid glove.

The manufacture of gloves and mittens in America was not undertaken extensively until just before the outbreak of the Revolutionary War. In 1760, a colony of immigrants from Scotland settled in what is now Fulton County, New York, establishing a village which they called Perth. Many of these newcomers had been glove-makers at home, and brought with them their patterns, needles, and thread. While they came as tillers of the soil, these former glovers devoted their spare hours, from work in the fields, to making coarse mittens and gloves which they sold to their neighbors on the adjoining farms. Skins were to be had in abundance, particularly buckskins, which were ideal for making into tough, serviceable mittens, adapted to the needs of farmers and hunters.

It was not until 1809, however, that gloves were manufactured for outside markets, and glove-making began taking the form of an independent industry. About this time a storekeeper named Talmadge Edwards took with him a bag of gloves on horseback to Albany to be exchanged for merchandise. Finding a ready sale for these, he employed a number of girls from the neighboring farms to cut gloves in his little factory, sending these out among the farmers' wives to be sewed. The year following gloves were sold in dozen lots by a former associate of Edwards, this being the first recorded instance of "wholesale" glove-traffic in America.

Other glove factories were soon established, and followed the lead of these pioneers in sending out wagon-load lots of their products. In 1825, a wagon-load was sent as far as Boston from Gloversville in Fulton County, New York, and sold at a good profit. Thus the region about Fulton County became the center of the American glove industry, and still remains so.

In the early method of manufacture, a skin was first marked out by means of pasteboard models, or patterns cut from thin pieces of wood. As graphite pencils were then unknown, the glove-makers used "plummets" of lead, made by molding the soft metal in narrow grooves. The gloves were then cut out with shears and wrapped up in bundles containing needles and thread, ready for sending out to the sewers. The cutting was usually done by men and the sewing by the women, although this was not always the case.

For many years no sewing was done in the factories, but only by piece-work by persons working at home. This sewing was done by a square-pointed needle threaded with a waxed linen thread. Between the edges to be joined a welt of buckskin was placed in the heavier gloves, although no welt was used in the lighter gloves and mittens. The finer gloves were backstitched, and had a "vine" worked on the backs, and were well fitting and serviceable. When the glove was finished it was placed between pasteboards and pressed, the pressing usually being done by the weight of the seamstress who sat upon it.

The method of marking out the gloves from patterns, and cutting with shears, was slow and expensive, and careless cutters frequently ruined the skins. But this method was soon superseded by the use of dies for cutting, which greatly shortened and simplified the process.

These dies were made of metal, with cutting edges like a cooky-cutter, these edges corresponding to the marks made by the "plummets" when the patterns were used. With such dies no marking was necessary, and a single blow of a wooden maul upon the die performed the work formerly done with the shears. In this manner the time of cutting out a glove was reduced from several minutes to seconds, accuracy and uniformity were insured, and spoiling the gloves by a miscut was impossible. These dies were first made in pairs for cutting out left- and right-hand gloves, but one was soon found to answer every purpose, cutting either right or left by simply reversing the leather.

This innovation greatly shortened the process of manufacture, but as every stitch had to be taken by hand, it was still slow, and the cost of production correspondingly high. In 1852, however, sewing-machines were introduced for stitching some parts of the glove and these were gradually improved until in 1856 a machine was perfected that sewed every part of the glove as well as it could be done by hand except the vine on the back.

The Civil War gave a great impetus to glove manufacture in the United States, as such a great number of gauntlet gloves were required for military service. The impetus given the industry at that time, together with the introduction of so many different kinds of machinery of American invention, has helped it to become one of the great industries of the country. It was not until about 1875, however, that steam-power was introduced for running sewing-machines, and this is now being largely replaced by electricity.

When the glove industry was in its infancy in America, the most common material for glove-making was buckskin. Deer-skins were cheap and abundant at that time and admirably adapted to making coarse gloves and mittens, which were practically the only kind manufactured. As the industry increased, and deer-skins became correspondingly expensive and difficult to obtain, other skins were pressed into service, notably sheepskins. Gloves made of this material as prepared at that time, however, were of very inferior quality and never became popular either for coarse gloves for rough usage, or for the lighter and finer kinds. But a little later better methods of tanning were discovered by means of which very serviceable gloves could be made from sheepskins, and at present most of the gloves and mittens manufactured are made of this material.

Other leathers have also come into use extensively owing to improved methods of tanning. The finer gloves for street wear are now made from the skins of such animals as colts, calves, lambs, kids, goats, South

American kids, chamois, and reindeer. Mexico, Central and South America furnish most of the deer-skins, although a large supply still comes from the woods of North America. Most of these skins are brought to the United States as raw hides, and are tanned in American tanneries.

Just after the close of the Civil War gloves made of "vat-liquor-dressed" antelope-skins became popular. But, as we have seen, about this time the antelope began to disappear, and it was no longer possible to supply the demand for this kind of glove. Fortunately at this time two bales of skins of an unknown variety arrived in America, coming from Arabia with a consignment of Mocha coffee. When tanned these proved to be a good substitute for antelope-skin gloves, and an effort was made to discover their source. They proved to be from a breed of sheep raised on the Arabian side of the Red Sea, and from their association with the consignment of coffee with which they first arrived, they came to be known as "Mocha" skins. Large importations followed, and at present this kind of skin is used extensively in the manufacture of fine gloves.

As referred to a moment ago, there have been revolutionary changes in methods of tanning hides during the last twenty-five years. At first, the Indian method of tanning was employed almost exclusively. In this the brain of the deer was used, producing a soft, tough, pliable leather; but as this material was hard to obtain in sufficient quantities, the brains of sheep and hogs were substituted. Curiously enough, neither of these gave satisfactory results, although the reason for this is hard to understand, since the sheep is so closely related to the deer.

Fortunately at this stage of the process, chemistry came to the aid of the tanner, and various chemical substitutes were found for deer-brains. Without entering into details, it suffices to say that an elaborate and extended process of soaking, washing, and coloring is necessary before they are ready for delivery to the glove-maker.

The first process of the glove-maker is that of "hand-staking" the skin. This consists in placing the skin in a device consisting of two upright and two horizontal bars, one of the latter being movable to admit the skin, and held in place by a wedge. The skin is then stretched by pressing upon it with a blunt, spade-shaped iron, having a handle made to fit under the arm.

When sufficiently stretched the skin is split by various methods, or shaved down to the required thickness. A peculiar method of shaving down the skin is by what is called "mooning." In this process a peculiar knife is used, being "shaped like a plate and having the center cut out and a handle placed across the opening." This is drawn over the skin hung on an elastic pole until the desired thinness is obtained. The skin is then ready for either the "block-cutters" or the "table-cutters."

In block-cutting the skin is laid on a block of hard wood, a die of the required shape placed carefully upon it, and given a blow with a wooden mallet. This kind of cutting is done mostly in the coarser grades of gloves.

Table-cutting is practically the same process, except that tables take the place of blocks, and the skin is dampened and stretched to exactly the right degree, this process requiring much skill and practice. To be a good table-cutter—that is, to be able to handle the leather so as to get the greatest number of pairs of gloves out of each skin, avoiding flaws, and stretching it to the proper degree—requires long practice, and is at best only attained by one workman in every three or four. It is the kind of work better adapted to foreign workmen, Americans not taking kindly to it as a rule.

From the cutters the glove goes to the "silkers" who embroider the back, and is then passed on to the "makers." Each maker has his particular work to do, certain ones sewing in the fingers and thumbs, others hemming the glove at the edge around the wrist, while the "pointers" work ornamental lines on the back. All these operations, of course, are done largely by machinery. The gloves are then drawn over metal "hands" heated by steam, shaped, and given a finished appearance.

One of the most remarkable machines now used in glove-making is the multiple-needle machine for stitching the backs of gloves. This machine sews from two to six rows at the same time. An automatic trimmer is attached to the head- or needle-bar of the machine which trims the gloves much better than can be done with shears. Other recent machines make ornamental zigzags, and overstitches, the latter closing the seam from the outside.

VI

THE EVOLUTION OF THE DWELLING HOUSE

TACITUS tells us that in his day the Germans crouched in dens dug out of the earth, and if this be the case, these people must have been of the type that resolutely sets itself against all progress, for the very first human beings of whom we find any trace lived in precisely the same manner. The earliest habitations of men were, in all probability, holes dug in the earth and covered with the branches of trees. Near Joigny in France, some of these dwellings may still be seen. They are circular holes about fifty feet in diameter and between sixteen and twenty feet deep. At the bottom, in the center, was fixed the trunk of a good-sized tree, the stem rising above the ground, where branches plastered with clay formed the roof.

These holes have been found in many parts of the globe, and were probably more important to their inhabitants as a hiding-place than as a shelter from the cold, for everything points to the fact that during their period of occupation the regions so inhabited enjoyed a mild or warm climate. The men who lived in the La Plata region of South America did indeed find a more protective substitute for the arboreal roof in the shell of the giant armadillo, or glyptodon, which was of a size to house them in quite comfortably; but nowhere else is there any reason to believe that the first dwelling of the human race was otherwise than the construction described above.

Climates, however, change, and man in the course of time not only found himself compelled to cope with colder weather, but he himself pushed further and further into more rigorous climes. Then it was, the hollow den failing his needs, that he learned to use the caves which are found in limestone rocks, and which he took as they were or enlarged to meet his requirements. The date of this important transition it is quite impossible to determine, but the archæologist places the cave men in the second period of the development of the dwelling, since in none of the caves have been found implements so primitive in type as those of the excavated dens. And moreover, as reckoned by time, the day of the first cave dwelling must vary greatly in different localities. When we speak of the "Early Stone Age" and "Late Stone Age" we should think of phases of human development rather than of fixed periods of time. To the present environment of some races of men living on the earth the term Neolithic would not be inappropriate.

In the cave, man found himself the rival of the bear and other beasts of prey in the somewhat precarious refuge, but nevertheless it is evident from the first that what best suited the needs of the one was that sought for by the others.

"Our ancestors must constantly have disputed the possession of their caves of refuge with animals," says a noted archæologist, "but there is often a certain distinction between those chiefly occupied by men and the mere dens of wild beasts. The latter are generally more difficult of access, and are only to be entered by long, low, narrow, dark passages. Those permanently inhabited by man are wide, not very deep, and they are well lighted. That at Montgaudier, for instance, has an arched entrance some forty-five feet wide by eighteen high. The cave-men had early learned to appreciate the advantages of air and light.

"The caves are often of considerable height; that at Massat is some 560 feet high, that of Lherm is 655, that of Bouicheta nearly 755, that of Loubens 820, and that of Santhenay is as much as 1,344 feet high.

"We soon begin to find evidence of the progress made by man, and though in Neolithic times he still continued to occupy caves, he learned to adapt them better to his needs."

In the Petit Morin Valley, for instance, "the shelters used to live in are divided into two unequal parts by a wall cut in the living rock. To get into the second partition one has to go down steps cut in the limestone, and these steps are worn with long usage. The entrance was cut out of a massive piece of rock, left thick on purpose, and on either side of the opening the edges will show the rabbet which was to receive the door. Two small holes on the right and left were purposely used to fix a bar across the front to strengthen the entrance. A good many of these caves are provided with an opening for ventilation, and some skilful contrivances were resorted to for keeping out the water. Inside we find different floors, shelves, and crockets cut in the chalk. Everything proves an undeniable improvement in the conditions of life."

The Marquis de Nadaillac notes that when man reached that stage of his development, which, according to the character of his implements, we call the Neolithic or Late Stone Age, he "still continued to occupy caves," but there is good evidence that at this time these were not his sole form of habitation. All over Europe and America, too, there have been discovered curious mounds not of natural origin which, when investigated, have proved to be refuse heaps (the oldest belong to the Neolithic Age) piled up by primitive man. Kitchen-middings they have been called, and they have yielded an immense amount of shells, bones, charred wood, stone implements, hearth-stones,—in fact, refuse of all kinds, to the extreme joy of the archæologist, and the enlightenment of mankind as to the habits and customs of our early ancestors. Their very nature and existence indicates clearly that they belonged to settlements, the habitations of which have quite vanished, but which were huts made of branches and dried clay, or tents of the skins of animals slain in the chase. Man had reached the stage where he was able to live in a more or less organized community, and the kitchen-midding shows that he had reached the dignity of a fixed abode.

Late in that period when human beings hewed their necessary implements from stone, and more frequently in that which marks the transition to the use of metals, we find a people characterized by their habitations. The "Swiss Lake Dwellers" they are called, but actually they lived in many other parts of the world as well. Austria, Hungary, Italy, Germany, and the British Isles contain many traces of them. Just why they should have gone to the trouble of building their houses beyond the shores of the lakes has never been determined, but indications point to a race or period of war-like activity, which made an isolated refuge one of the prime factors of existence.

The Swiss bodies of water are dotted with these stations. The lake of Neufchâtel has forty-nine of them; Constance, thirty, and Geneva twenty-four. Three different periods of Swiss lake dwellings have been noted, characterized by their distance from the shore. It would seem that whatever the motive that impelled the building of these aquatic settlements, it acted more powerfully as time went on, driving the inhabitants farther and farther from the shore, until new conditions changed their mode of life or they succumbed to the fate they tried so hard to escape. The oldest of the settlements are located from a hundred and thirty to three hundred feet from the shore, the latest from seven hundred to a thousand feet. They were built, naturally, on piles, which were about eleven or twelve inches in diameter, pointed at the ends and hardened by fire. When these piles had been driven into the bottom of the lake a platform made of beams and bound together by interlaced branches was laid on them to bear the weight of the huts. The depth of water under the huts is on the average about fifteen feet and varies but little from that figure. The dwellings themselves were made of interlaced branches, or of clay and straw; they were rectangular in shape, divided into two compartments connected by a foot-bridge of three beams laid side by side. The floors were of rounded wood, and the walls of piles split in half. Sometimes several floors rose one above another divided by thick layers of clay.

Such, in brief, are the main features of one of the earliest homes of mankind. We, of the favored races, enjoying our highly developed dwellings, are apt to refer these ways of living to a very remote past. But, as has been said, to a considerable portion of the human race the terms Stone and Iron Age are still applicable. The hut of the Eskimo, the wigwam of the American Indian; the habitation of the African savage and the nomadic tribe of Central Asia, afford much information as to the dwellings of our primitive ancestors. Even the Swiss lake dweller, in whose difficult struggle for existence we take perhaps more interest than in that of any other primitive man, could he come back to-day, would feel at home in some parts of Oceanica and Africa.

Until within the last half century the style of architecture as well as the material used in building, even in city dwellings, was largely determined by the natural products at hand, and aside from the comparatively few dwellings of the wealthy, this is still a determining factor to a large extent. The Eskimo, utilizing the material at hand, builds a house of snow; the Egyptian uses reeds and rushes; the Greeks and Romans, living in a sparsely wooded country, built stone houses; the Assyrians, having but little stone at hand, learned to make brick; while the Teutonic dwellers in the north, surrounded by forests, built their houses of wood. Even the very wealthy in these lands in times past had little choice in their building-materials, and while no such restriction is placed upon the very wealthy to-day, the generality of people the world over still build their houses of the material nearest to hand.

It is always true that the farther we go back in the history of an art the more simple and direct are the forces that we find attending its development. How close the savage lived to the primitive powers of nature is scarcely realized by members of civilized society. His life is directly molded by geography, geology, and climate. His art is created from suggestions given by his own environment, interpreted and applied according to the powers of his intelligence. Thus we find the aborigines of wild forest-belts building their huts of log platforms with a wall of interlaced branches on the windward side alone; we find Arctic hunting tribes—such as the Eskimos of Kamchatka—forced by the cold to hang the skins of animals on the walls of their conical dwellings.

In the architecture of the cliff-dwellers we have a fine example of the utilization of natural opportunities. The southwestern portion of the United States is known to the geologist as the "plateau country." Its dominant formation is the *mesa*, or flat mountain-top, furrowed by chasms varying greatly in breadth. The walls of these gorges are perpendicular, rising from ten to a hundred feet in height. At their feet lie rich alluvial lands deposited by receding floods.

What could have been more natural, more economical—more inevitable—than the utilization of these laminated cliffs as dwellings by the Pueblo Indians who cultivated the areas below?

Though the earliest forms of human habitations may be less ingenious than much of the architecture of the birds and the animals in structure and design they, nevertheless, possess greater interest for us not only by reason of what has been developed from them, but because by working backward, so to speak, we are able to trace architectural forms and designs through them directly to their origins in nature. When analyzed, the different styles of architecture are seen to be descended even in their latest developments from the building materials of the days of primitive effort. In the earliest period of Egyptian civilization, there rose along the alluvial deposits of a great river an architecture of reeds and mud. Parallelograms were built of bundles of reeds tied together at the top and set upright at intervals; spanning these lay a straight roof, suitable to the dry climate, made also of reeds and strengthened with clay. The pressure of the roof upon these reed pillars was resisted by a horizontal rule laid on top of the pillars. This is, obviously, the origin of the cornice. When stone began to be used the old pillar of clustered reeds, tied at the top, and bulging below, was rigorously copied. Moreover, on the mud structures ornamentation in high relief was clearly impossible, and we see in all Egyptian architecture a predilection in favor of the engraved figure and the hieroglyphics suitable to its first structures.

Assyrian architecture developed forms dependent on small units of construction. Possessing little timber, and practically no stone, they baked the soil into bricks of uniform size. These made solid walls, which, however, did not lend themselves to carvings or decorations in relief. The Assyrian method of ornamentation was, therefore, during its entire history, the superimposed slab of alabaster or granite, or a coating of highly glazed, multi-colored bricks. Moreover, a structural problem was created by the exclusive use of the small brick. In the absence of long timber beams and of large stones the erection of a second story, or even of ceiling and roof, became difficult. Necessity, therefore, forced upon the Assyrian the beautiful solution given by the arch.

The Greek edifice is essentially adapted to the use of large stones jointed together without mortar. This method was transferred to Rome, and governed construction till the last century of the old era, when radical transformations were wrought by the invention of a concrete formed of pebbles and mortar. The arch, devised in Assyria, was marvelously developed by the Roman mason, who had the plastic concrete to work with. Elaborate vaulting made necessary an accurate science of abutment, and gave rise to forms of great complexity. Ornament was no longer a part of the body of the structure as with the Greeks, but became a drapery for the undecorative concrete of the original wall.

It will be seen, then, how the great essential differences in the architecture of Egypt, Assyria, Greece, and Rome were due primarily to the geological formations of the regions in which they originated. When civilization had forced its way into the almost limitless forests of Northern Europe, a typical timber architecture was developed which later adapted some of its peculiarities to edifices of stone.

By the thirteenth century Gothic architecture had reached a marvelous stage of development. But the stone used was no longer the granite and marble of the ancients. The material had a tendency to split and crumble. This reduced the unit of construction, and still retained the arch which now assumed a pointed form.

The various architectural styles have been developed, therefore, through the acquisition of knowledge of the properties of materials, and their use in the manner indicated as best by this knowledge. Of course, other forces than those purely physical operated in architectural development, and of these the most powerful and noteworthy have been those created by political creeds and social customs. All of these enter into the evolution of the habitation or dwelling-house.

Habitations were originally designed as a shelter from the elements. The form of shelter which, naturally, would suggest itself first was that which called for the least ingenuity; namely, a conical structure of logs and boughs with walls and roof as one element. When the inevitable demand for increase of size made itself felt, there were two ways to meet it; by increasing the circumference and retaining the circular form; or by dividing the structure in two, separating the portions and erecting sloping side walls to join them. The latter method gave a ground plan in the shape of an elongated rectangle with two semi-circular ends. It is clear that this rectangle could be lengthened indefinitely by adding to the sides sections or "bays." From these bays, ells, wings, towers, and other additions have been developed, but they are, after all, only excrescences on the rectangular ground-plan.

A village unearthed near Glastonbury, England, revealed a collection of conical houses built of wattle-and-clay, dating all the way from 300 B.C. to the time of the Roman occupation. These houses are almost precisely like those of prehistoric times found in Northern Italy, and they have their counterparts in Ireland and Scotland, where several of them are often united. They are like the primitive hut in form, and differ from it only as their structural materials may require a more ingenious manipulation. They represent the first step in house-building; and it is interesting to find that the conical shape persisted even after stone was used, and after the floor was divided into apartments. This was, of course, due to the fact that the imitative faculty was stronger than the imaginative.

The inadequacy of the primitive dwelling to meet the rigors of winter led to the development along other lines, the construction of pit dwellings, or caves, sometimes two stories in height, sunk from three to ten feet below the surface of the ground, and entered by horizontal tunnels. Their roofs were made of interlaced boughs and clay. A series of these caves was often united by subterranean passageways, as may be seen in certain ruins near Bologna, Italy. Such habitations are still built in the valley of the Euphrates.

The rectangular structure in its simplest form consisted merely of two bent trees set opposite each other in the ground, their apexes joined by a ridge-pole. It is thus suggestive of an inverted boat. It had no walls, except the gable-ends, and its roof sloped to the ground. The bays were thrown out between the bent-tree arches, which stood always sixteen feet apart. This distance of sixteen feet was not accidental; it was exactly the space required for four oxen to stand abreast, and these bays were used as stalls. The bay thus became a unit of measurement, and it still does service through the medium of its modern equivalent, the rod.

The primitive structure received a notable modification when its sloping roof was shortened and perpendicular walls erected. This was done by lengthening the ends of the tie-beam, until it was the length of the base of the arch formed by the two trees. Then long beams, called *pons*, or *pans*, were laid at the ends of the beams and rafters placed between the *pons* and the ridge-pole. After this the erection of a wall was easily possible.

The first walled houses were built of wattle-and-daub, then copied in stone and brick. In a somewhat highly developed condition the early walled houses were built on this plan: Within the doorway, which was on the street, stood a covered porch with a screen at the back; this screen, known in England as a speer, had a bench at its base and a shelf along its top. Behind it lay the floor or threshing-floor, which resembled, in shape and position, the Roman atrium, for on its two sides were built apartments facing inward. In the case of the house we are considering these apartments were used as stalls, and a fodder-trough lay between them and the threshing-floor. On the right of the entrance stood the cows, and over their heads were built into the wall the bunks of the women servants; from the left the horses gazed over at the cows, and above their heads were the sleeping-niches of the men servants.

The back part of the threshing-floor was the sanctum of the family, and contained the hearth, at the right and left of which were the berths of the men and women of the family. This apartment was called the fire-room. At each end of the building a ladder gave access to the uncovered second story—uncovered of necessity, for the chimney had not yet been invented, and an open space to the sky for the escape of smoke was essential.

This plan was later modified by transferring the entrance door from the gable-end to the side wall, and separating the threshing-floor from the fire-room by a vestibule. These changes, slight and superficial as they really were, greatly obscured the basilica plan from which the dwelling sprang, and which in reality, though not in appearance, it retained. Vitruvius, who wrote in Rome during the age of Augustus, speaks of dwellings built on this model, and Galen describes similar houses in Asia Minor in the second century of our era. The type still exists in Friesland and in Saxony, and also in Yorkshire, where it is named a coir.

In the British Museum is a model of an Egyptian house consisting of a first floor with pantries and chambers built around a central court, and a staircase; this staircase leads to a chamber above, of which the second story consists. It is not difficult to see the analogy between this structure and the rectangular cattle shed. The Egyptian house possessed a portico with massive columns; its doors were multiplied and stained fantastically; the intercolumnar panels which were its walls were decorated; mottoes were painted over lintel and impost; balconies were thrown out; its window-facings were carved. But all this developed logically from a simple court with chambers facing inward.

The Assyrians disguised the same primitive plan by building on terraces as a protection against floods, whence came the first motif of Assyrian architecture. The ruins of the palace of Persepolis, which show the Persian adaptation of the Assyrian style, rise on platforms of rock along the foot of a mountain, and each terrace is surrounded by huge, irregular blocks of marble. A balustraded staircase, twenty-two feet wide and containing one hundred and four steps to the first terrace, gives entrance to the western end of the building. At the summit rise two great pillars with colossal low reliefs. A court with four columns leads to a second portico. At the right of this is a cistern hollowed out of the solid rock, into which water was brought by subterranean ducts. Then the staircase continues, and the terraces repeat themselves in variation of design.

The Greek house, with its double-court construction, is a familiar type of dwelling. On entering his house from the street, the Greek found himself in a vestibule from which he gained a vista of the colonnaded apartment of the men. To the right and left were doors opening into pantries and servants' apartments. Crossing the vestibule he entered a square or oblong court, opening to the sky, and surrounded by apartments—libraries, art-galleries, dining-halls, bed-rooms, etc. The plan reminds one of a steamer's cabin surrounded by staterooms. At the rear of the court, to the right, a staircase led to the second story, similarly designed, but only partially spanning the ground floor. Through a second vestibule he entered a second court, opening out in the same manner into apartments on each side. At its rear lay a garden on which the most elegant of the guest-rooms faced. This inner court was formerly supposed to have been exclusively the house of the women, not unlike the Oriental harem, but recent investigation has established the belief that it was the place of the family life.

The Roman house also passed through the same stages as that of other countries. There was the hut; and—instead of the inverted boat—the parallelogram with the flat roof used as a garden and pleasure ground; the house of many courts, which grew into a very forest of columns and arcades; an enchanted land of line and color with carvings, paintings, mosaics, entablatures, gildings, terra-cottas, and fountains.

The difference between the country and the city house which now exists has always existed in some measure. It may, however, be accepted as a general proposition that the country house tends to spread laterally and longitudinally, the city house perpendicularly. In the narrow streets of the Middle Ages a form of city architecture developed which, striving after light and air, hung one story out beyond another, so that the profile of the house was like an inverted staircase. This style was fostered by the custom of having booths at the front of houses for the display of wares. These wares showed to advantage in the jutting stories, till the street became so darkened by the over-arching gables that the purpose of the style was quite defeated. In these structures we first see the tendency to turn the face of the house outward upon the street.

After the close of the Roman occupation timber architecture prevailed in England till the feudal castle was introduced after the Norman conquest. When Alfred the Great rebuilt London and founded the University of Oxford he built of wood and thatch. The timber used was oak, framed together by mortice and tenon. The gaps in the framework were filled in with clay, and with straw plastered over. The foundation was usually a three-foot stone structure.

The nucleus of the feudal castle was the tower. Its battlemented turrets gave wide views over the surrounding country, and in its depths dark deeds could be perpetrated without probability of their being revealed. A central tower was connected by walls of masonry, often twenty feet thick, with end towers, toward which at right angles again ran massive walls till the familiar quadrilateral court was formed once more. These walls were frequently four or five stories high. This fortress finally gave way to the palace of the Renaissance, and it is interesting to note the survival, in a transmuted form, of the martial tower in the decorative *tourelle*—the turret and oriel—of these peaceful and ornate mansions. When Henry VIII confiscated the monastic institutions of England, many convents were turned into manor houses. Domestic architecture in England now became enriched; gables increased, pediments appeared over gable windows, and these were molded and adorned with pinnacles, finials, and vanes. These weather vanes were often musical boxes wound by the breeze.

So far we have considered the dwelling-house as a whole. If we turn to the individual parts, we find that each has a separate and interesting historical development of its own. We have mentioned that the erection of complete upper stories was impossible prior to the invention of the flue. It will be interesting to inquire when this particular construction, which to the modern world seems indispensable, was first used. Its origin depends, of course, upon one's definition of the term "chimney." In its most radical sense it can be extended to comprise a hole in the ceiling or wall for the escape of smoke, and these holes were probably contemporaneous with the discovery of fire. The translator of the third verse of the thirteenth chapter of Hosea, for instance, has rendered as chimney the Hebrew word *arubeh*, which means a hole or opening, or, specially, a window. Such looseness of terminology is, however, deceptive; a chimney should signify specifically a flue built up along a wall and raised above a roof. In this sense chimneys seem not to have existed prior to the fourteenth century A.D. Vitruvius warns the Romans against elaborately carved cornices in the fire-room, on account of discoloration from smoke. The houses of Pompeii and Herculaneum, which have taught us most of what we know regarding the Roman and Greek house, present no trace of chimneys. Seneca tells us that whenever a feast was held special watchmen were appointed to keep guard over the house of entertainment, lest disaster should result from the unusually ardent blaze in the kitchen.

Columella gives directions for the height of ceilings in order to minimize danger from fire. This would all have been unnecessary, of course, had chimneys existed in his day. The preparation of wood in ways to diminish the amount of smoke given out in combustion, constituted a Roman industry. Nor was the smoke, which could not be done away with, regarded altogether as a waste product. Around ancient kitchens are found places for smoking meats and wines; and coops for a certain breed of fowl supposed to thrive in smoke! We read of eye-diseases due to smoke; Horace was once afflicted with one.

Chimneys first enter written history in an account of an earthquake in Venice in the fourteenth century, when several are said to have been thrown down. In his history of Padua, written about 1390 A.D., Galeazzo Cataro tells the story of a Paduan nobleman who went to Rome and put up at the "Sign of the Moon."

Suffering from cold, he sought a fire and could secure nothing but a brazier, the fumes from whose smoldering wood blinded and choked him. Disgusted with the unprogressive spirit of Rome he sent to Padua for masons, whom he ordered to build two chimneys in the inn. These were the first chimneys erected in the Imperial City.

Chimneys were soon adopted in the castles of England, and, in consequence, the hearth, which formerly stood in the middle of the room, was moved to a side wall. They were at first constructed of wood, but in 1419 this material was prohibited. For a long time the chimney remained closed at the top, the smoke escaping through perforations in the sides. Fires were by law extinguished at a certain hour in the evening. This custom gave origin to the curfew-bell, which had nothing to do with prayer, but only with municipal safety, the bell announcing the hour for putting out the fires.

It was not till the sixteenth century that the use of chimneys in dwelling-houses became general. The Turks and Greeks of to-day do not use them, but perpetuate an old Persian method of heating. They dig a hole in the ground and set in it an iron vessel, square or round, and two spans in depth. When a fire of coal or wood is well started they place over the little stove a sort of table, and over this table a covering, a kind of quilt which retains the heat. Around this stove sits the family. The fire is kept active by means of a pipe which enters the stove at one point and emerges from the floor at the other; this is in fact the prolonged funnel of a bellows which is attached to its outer end. By the addition of metal plates this arrangement becomes serviceable also for cooking.

It is curious to find that the principle of the hot-air furnace was discovered prior to the seemingly simple device of the chimney. In the time of Seneca, Roman baths were equipped with underground stoves from which hot air was conducted by means of pipes around the walls of the building. These pipes opened into the rooms by apertures similar to registers, except that they were so designed as to be ornamental. They were usually carved in the form of animals' heads.

The excavations at Pompeii and Herculaneum have thrown more light on the private houses of antiquity than it was possible to receive from literature. Till recently it was believed that the use of glass for windows was of modern origin, but the discovery of a sheet of plate glass at Herculaneum gives us one more glimpse of the finished civilization which existed before the Christian era.

The origin and early history of glass manufacture is obscure, but we do know that the first glass factory known to history was at Tyre. Glass was known at Rome in the time of Tiberius, when an artist was alleged to have discovered the secret of making it flexible. For this miracle he was condemned to death. Glass was used for ornaments and for household utensils in the barbarous island of Britain before Cæsar and his legions entered it, but it was not employed for windows till after the Norman Conquest, and then only in dwellings of great elegance. During the reign of

Henry II it began to be more generally substituted for the oiled paper, the cauls of colts, the canvas, and the opalescent shells which had heretofore covered window openings, and which even to-day are to be seen in remote districts of Italy where glass is still too great a luxury for general use. In the sixteenth century huge glass windows became an expensive fad in the residences of the English nobility. We read that "Hardwick Hall had more glass than wall!" Windows were not then considered part of the house, but were disposed of separately in the wills of the owners. They were covered with tracery, and set in casings of brick faced with flints, stone, or black-glazed bricks.

In the dry climates of the East roofs are often flat. The flat roof of modern Turkish houses is equipped with a cylindrical stone roller, which after a rain is rolled backward and forward over the surface to dry it. The ancient Egyptians built their roofs flat, but the Greeks had a roof like the letter A, which they covered with slabs of marble. The Romans used this same style of roof, and finished it with parapets and balustrades. The roofs of the Roman court were of five varieties. Three of these sloped inward, leaving in the center a flat area for the collection of rain water; the fourth variety covered the entire atrium and sloped outward, allowing the rain to run into gutters and thence into drains which led the water away from the house, or into subterranean cisterns; the fifth variety was probably made of plate glass. The long roofs in the timber districts of Germany and Switzerland are extreme illustrations of protection against storms. The covering of roofs received great attention from beauty-loving antiquity. Semicircular tiles overlapping each other, so as to produce pleasing effects of light and shade, were in great favor. The architect of the Middle Ages carved his ridge and gable.

We do not know how the ceilings of the ancient dwellings were ornamented, but we read of the magic panels in the ceiling of Nero's Golden House, which revolved, dropping flowers and perfumes. It is probable that ceilings were usually divided into compartments and painted, each compartment having its own design. Whitewash and plaster were commonly used as a foundation for decorative work. Ceilings, walls, and floors grew very ornate in European architecture after the thirteenth century, when Moslem influence was first felt. Arabesques in stucco, mosaics, paintings, variegated stones, and gildings suggested the splendors of antiquity. The walls of the Golden Saloon of the Alhambra are made of pebbles and red clay wonderfully combined. The arched ceiling of this hall is sixty feet and four inches high, and is composed of pieces of strong wood, keyed and attached so that the whole structure shakes from the slightest pressure at the summit.

The floors of ancient Egypt were built of stone, or of lime concrete. The rafters were of date trees, with transverse layers of palm branches. The floors built in England by the Romans were of colored earthenware tiles, and of glazed mosaics, but the Anglo-Saxon used flagstone or blue slate, and on this he drew patterns in chalk which disappeared at each cleaning, and were faithfully renewed by the housekeeper. Houses were then painted "archil" or vivid blue, combined sometimes with yellow. During Elizabeth's reign floors were so rough that a covering of rush or of tapestry was used, "defending apparel, as traynes of gownes and kertles from the dust." In the seventeenth century the old Roman floor was revived in England; this was made of hard white stones, about an inch thick, laid in cement.

Staircases were often made a sumptuous decoration in the house of antiquity, but in England, prior to the reign of Henry VII, they were secreted in towers, and considered merely as a means of ascent. They were then called turnpikes. But in the reign of Elizabeth they became a feature of great magnificence. A contemporary thus describes the stairs at Wimbledon palace: "The east stairs of Wimbledon lead from the marble parlour to the great gallery and the dining-room, and are richly adorned with wainscot of oak round the outsides thereof, all well gilt with fillet and stars of golde. The steps of these stairs are in number thirty-three, and one six feet six inches long, adorned with five foot paces, all varnished black and white and checquer-worke, the height of which foot pace is a very large one, and benched with a wainscot benche, all garnished with golde. Under the stayres, and eight steps above the said marble parlour, is a little complete roome, called the den of lions, floored with painted deal checquer-worke."

The doors of ancient dwelling-houses were low; the pyramidal shape, popular in Egypt, was sometimes used in Greece. Ancient doors turned on pivots, not on hinges, and this construction still obtains in the East. These pivots were sometimes of metal, but more generally of wood, like the door, and they worked in sockets. In Egypt doors turned on valves, which revolved round metal pins, many of which have been found in the ruins of Thebes. They were fastened to the door with bronze nails, whose heads were ornamented. The upper valve had an arm at the back to prevent the bruising of the wall. The effect of these is not unlike the Tudor strap-hinges, which were nailed, bolted, and riveted against the door, and ornamented. The present Egyptian lock is probably the one used in antiquity. It is sometimes of wood, sometimes of iron, and is opened by a key made of several fixed pins which correspond to an equal number of pins depending into the tongue of the lock. The first key of which we hear was made 1336 B.C. and was used in the summer palace of Eglon, King of Moab.

Most Egyptian and Greek doors opened inward, whereas Roman doors opened outward. They were all equipped with bolts and iron handles as well as locks. Secret doors were constructed with marvelous nicety during the feudal period. It is a curious fact that the hall of the Teutonic chieftain never had more than one door. To this architectural peculiarity the romantic novelist owes a large debt of gratitude. Caught in his cul-de-sac by an enemy, the chieftain had no means of escape. His ingenuity would seem to have been inferior to that of the rodent, who always contrives a hole of exit; but the argument probably was that two doors could not be guarded as securely as one.

Windows on the Continent swing outward on hinges like doors; in England they descend and ascend on weights as in America. But in modern architecture they are placed on the exterior of the building, whereas in ancient times they invariably overlooked the interior court. This constitutes the most radical difference between the ancient and the modern house.

It is commonly supposed that another great difference lies in the extent of the ground area in the house of antiquity, in contradistinction to our narrow structures, and in the height of our houses, in contradistinction to the low buildings of past centuries. These differences, however, are not as radical as they seem from the superficial description of the dwellings themselves. For instance, we read that the house of Pansa contained fifty rooms on the first floor, and immediately the image of an exceedingly large ground space is evoked; but in reality the house was only one hundred feet wide, and two hundred deep. The individual apartments were very small in the days when life lay nearer to the communal state than it does now. On the other hand, three stories were by no means uncommon, although the upper stories were not complete till after the fourteenth century.

We have seen that the original unit of the dwelling was the court, and that this developed into the hall of the Middle Ages—the huge banquet-hall, with a door at one end and a dais for the host at the other. With the growing individualization of life this hall became smaller and smaller, and the individual apartments expanded in inverse ratio, until we have that dark and narrow alley which in the modern dwelling is called a hall. This, though a common meeting-place for the occupants of the dwelling, is indeed an ignoble descendant of the stately apartment of the mediæval castle.

The new continent of North America inspired her builders to a distinct type of school of domestic architecture. In the Colonial houses there is the expression of thought and feeling very different from that expressed in the houses of other countries. In the breadth of door, window, and hearth dwells the sentiment of emancipation, and the sacredness of the family. The soft browns with which the houses are often painted and which recede into the browns of tree and ground, and the grays and whites which also are favorite colors, and which are as austere as Puritanism itself, tell the story of simple ideals.

Both necessity and inclination have made man use the greatest variety of material, both natural and artificial, in building his home. Necessity has played a far greater part than the other factor, however, particularly in the early stages of progress toward civilization. And even to-day there are so many restricting elements governing the building of habitable structures, that civilized man finds himself almost as badly hampered as his primitive ancestor in the selection of his building material.

Every man, whether savage or civilized, has to consider two great factors in selecting the material for his buildings—the elements, and his enemies of the animal kingdom. Indeed these are the two great factors that have forced him to go into dwellings at all. And the richest and most highly developed urban dweller is influenced by these two things almost as much to-day in the construction of his house, as was his primitive ancestor dwelling in his skin or mud hut on the shores of the Mediterranean. He does not fear the jungle night-prowlers that menaced the hut-dweller, to be sure, but he has to guard himself against other night-prowlers, quite as fierce and far more cunning than the four-footed ones of the jungle.

The one common enemy which baffled the ancient builder as it still baffles the modern, is fire. The dwellers on the equator, and those near the poles, are troubled very little by this enemy; but those living in intermediate regions must always have it in mind in choosing the materials for their homes.

Until comparatively recent times the problem of transporting building material long distances has been so great that the surrounding conditions determined largely the materials that would be used for constructing most of the buildings at any given place. But the advent of steam so modified transportation methods, and steam-driven machinery so facilitated the gathering of building material, that local conditions now have very little bearing on the material used in construction. In place of the Kansas squatter's adobe cabin, made of material gathered within a radius of a mile or less from his door, the fairly well-to-do Kansas farmer of to-day thinks nothing of building a modest house with cement that comes from Pennsylvania, lumber from Maine, brick from Missouri, and paint manufactured in New Jersey. He furnishes his house with articles that come from the four corners of the earth, and heats it with coal that has to be hauled fifteen hundred miles. Distance is no longer a determining factor as to material used in building; and this elimination of space from the problem has played, and is playing, an enormously important part in the selection of building material all over the world. Indeed we shall see a little later that it makes it possible, in many instances, for man to build better buildings, for less money, by using artificial products hauled thousands of miles, than by making use of the most natural and abundant ones furnished by nature close at hand, such as stone.

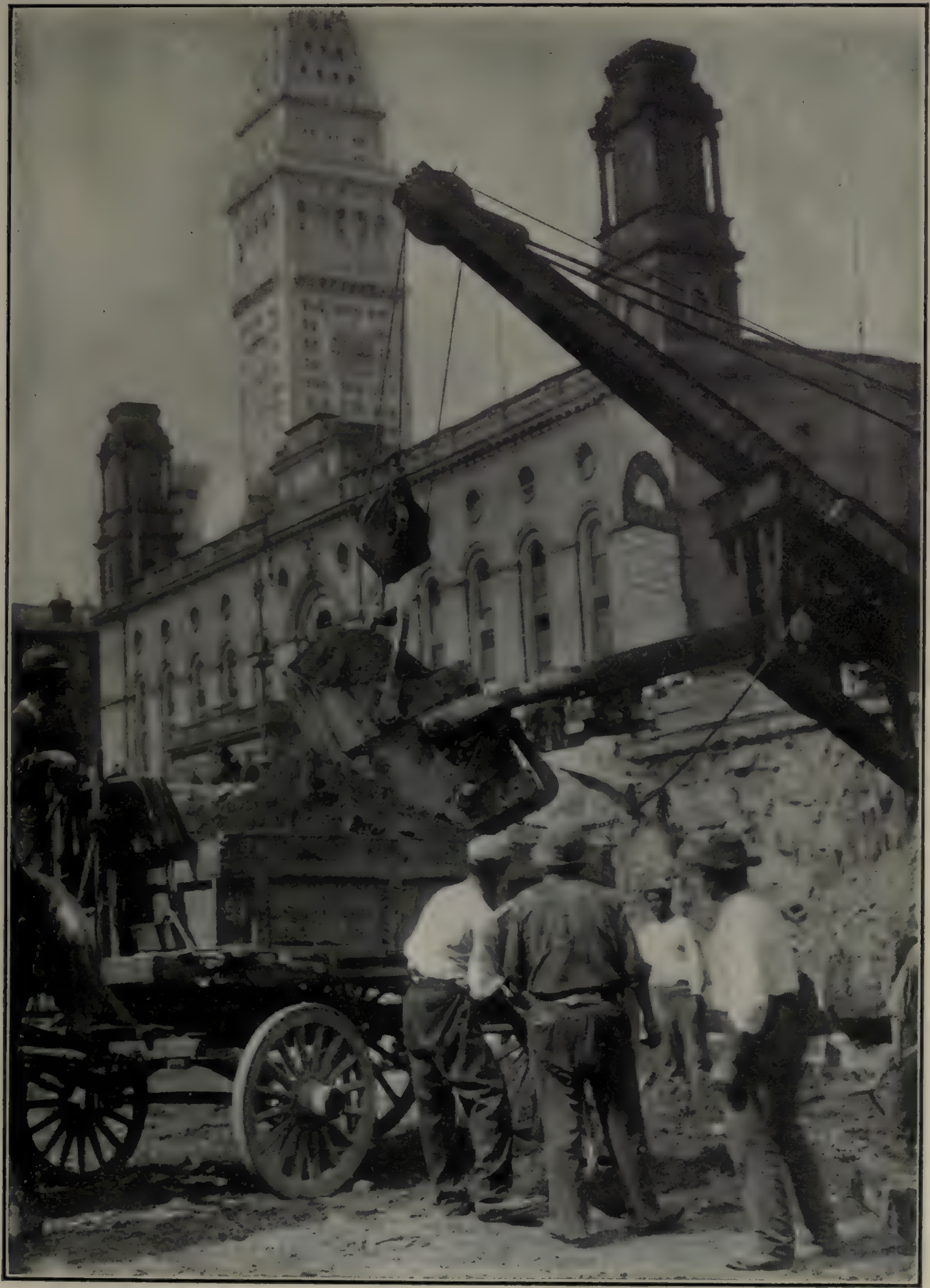
Until the closing years of the nineteenth century the materials employed in constructing buildings, and the methods of using them, had changed very little from those of the builders of ancient times. Wood, brick, and stone were in use as far back as we have the records of history; fire "brick" and even a form of cement used to form an "artificial stone" was known to the Greeks and Romans. The dome of the Pantheon, built two thousand years ago, is of this material, as is also the Aqueduct of Vejus. But in the last two decades of the nineteenth century great strides were made by the modern builders, who were then, for the first time since the beginning of the Christian Era, able to produce something new in the architectural world, by the use of steel and cement. The construction of a modern skyscraper would have been quite beyond the possibilities of any architect who lived prior to the present age of cheap steels. The Roman architect might have been able to raise a structure as high as the Singer Building in New York city, but he would have had to sacrifice all interior space for its support, just as in the case of the pyramids along the Nile. The greatness of the achievement of the late nineteenth-century architect does not lie in the fact that he can build so high, but that he can leave so much space in the interiors of his high buildings. The practical revolution in architectural plans and results made possible by the new methods will receive detailed consideration in succeeding chapters.

VII

THE MODERN SKYSCRAPER

THE average city office building of to-day is the outgrowth of dire necessity. Nothing short of that could have produced it; for man is essentially a terrestrial animal, whatever arboreal habits his ancestors may have had. Left unmolested by enemies, and with the stress of fighting nature for existence eliminated, he would seldom have built two-story buildings, to say nothing of structures of twenty, forty, or fifty stories. But fortunately for progress it has never been the lot of civilized man anywhere in the world to escape both these dangers at any one time. As a result upper stories have been added to his houses either as a means of defense or for economy.

At remote periods in history when land, building materials, and labor were cheap, there was no reason to add upper stories for the sake of economy; but in those times the element of danger from enemies was proportionately greater than in recent years. Predatory animals and men had always to be reckoned with; so that, although land and building materials cost little, it was necessary to raise protecting walls higher and higher in proportion to the importance of the tenant. The sky-scraping donjon, or keep, of the



EXCAVATING FOR THE FOUNDATION OF A SKYSCRAPER.

As seen here the steam shovel is about to discharge its load into the waiting wagon. The operation of scooping up the dirt and placing it on the wagon is done mechanically, one workman controlling the movements of the machine by means of levers.

mediæval castle, the highest occupied structures of the Middle Ages, was the product of danger.

But in modern times, since houses are no longer fortresses, economic reasons alone have forced builders to add more and more stories to their structures. Practical constructors roughly calculate the cost of a building by the spread of its roof, not by the number of its stories. It requires no more land, no larger foundation, and no more roofing material to erect a five-story building than to build a one-story structure of corresponding horizontal dimensions. And while, of course, every added foot of height adds to the cost of construction, this cost is far less than if the increase in size were in a horizontal instead of in a vertical direction.

During the first half of the nineteenth century the "normal height" of buildings in the country, small towns, and villages, was two stories; in the larger cities three, or even four, stories; and in the largest cities, five stories, except for ornamental purposes. At that time cities were relatively small and the percentage of persons living in the country relatively large. But the last half of the nineteenth century saw the people crowding into the larger cities in ever increasing numbers, focussing on certain centers, and overcrowding many districts so that the price of land in such places rose to fabulous figures. As a result it became necessary either to dig cellars deeper, raise roofs higher, or do both, to accommodate the population.

But now man's physical limitations offered an obstacle to unlimited vertical extensions in building construction. Four flights of stairs, to reach a fifth story, represent about the limit to which man would ascend for pleasure or business except when absolutely necessary. The case stood thus: higher buildings were absolutely necessary; muscular exertion refused to carry man higher. The implication was obvious—some substitute for muscle must be found.

The substitute took the form of the passenger elevator, introduced in 1853 by Elisha G. Otis; and this invention, and one other that came a quarter of a century later, made possible the modern skyscraper.

The development of the elevator will be referred to presently. The other invention was that of the steel-frame construction, with which it was possible to erect high buildings having relatively thin walls.

THE STEEL FRAME

By the old method of constructing with stone or brick, the walls of a twenty-story building would have to be so thick near the base that the rooms on the ground floor would be reduced to mere tunnels, scarcely wide enough for the staircases and elevator shafts. But by using steel girders and braces, and filling in the spaces with some such substances as tile, brick, or stone, a thin veneer on the outside, or a surrounding shell, the walls of a tall building may be kept of almost uniform thickness from base to top.

The steel frame of a modern skyscraper is really "a cantilever bridge stood on end." Perhaps the improved bridges of the early eighties suggested the steel-frame construction in buildings. Be that as it may, the work of the modern bridge-builder and high-building construction have much in common.

A transitional stage between the old-time masonry construction, and the modern "skeleton" building, was what is known as the "cage" construction. In this type of building which is now practically obsolete the walls are built of masonry and are self-sustaining, but the interior construction is carried by steel frames. This form of construction had scarcely been invented before it was replaced by the present form of skeleton construction, in which the steel frame forms a cage which is surrounded by masonry.

The first building constructed on this principle was the Home Fire Insurance Company in Chicago, designed by Mr. Jenny, in 1884, although Mr. Post, in New York, had furnished an example of the "cage" construction in the interior court of the Produce Exchange somewhat earlier.

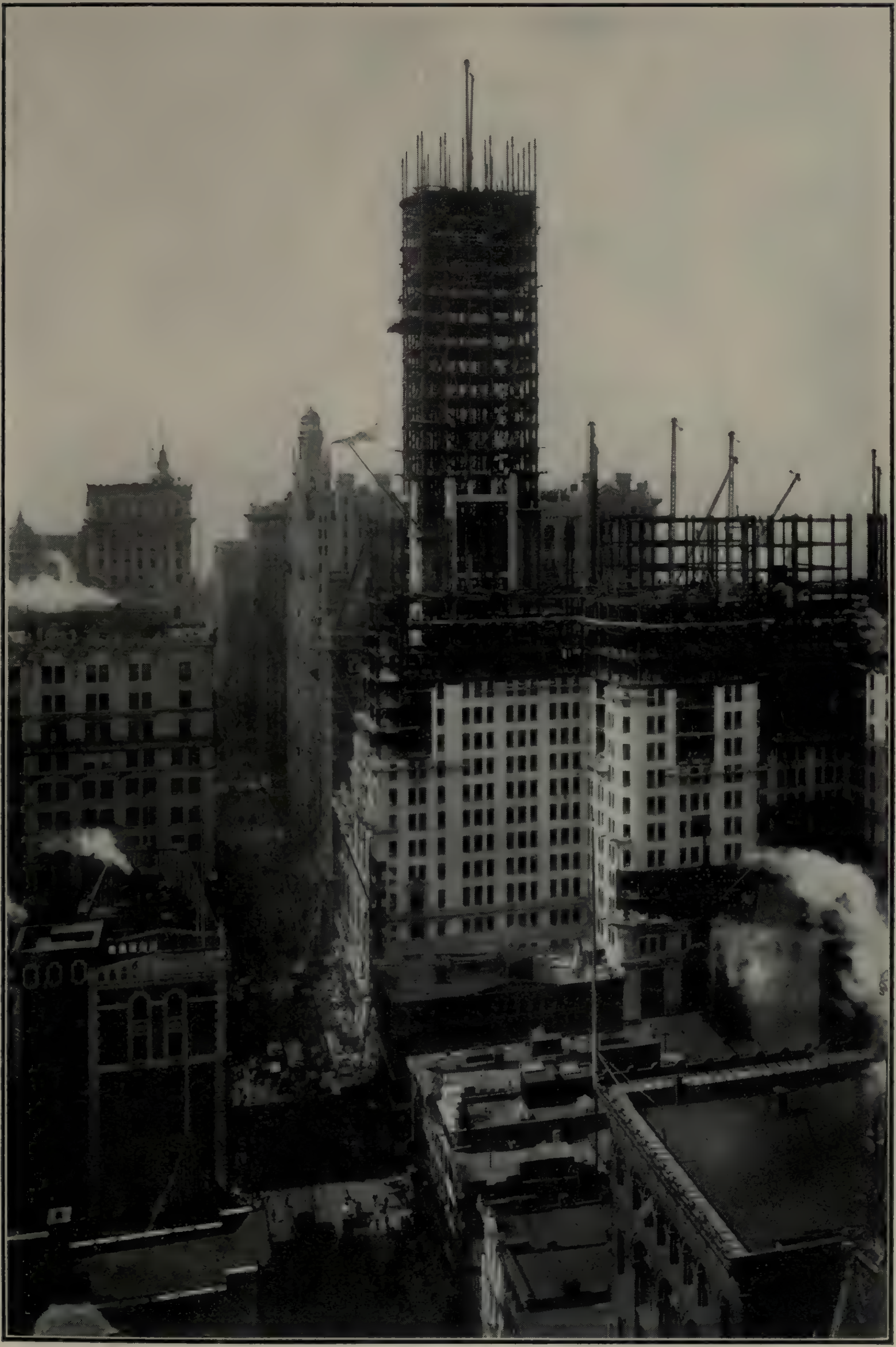
Just at this time the newly discovered Bessemer process had placed cheap steel on the market—another product of necessity, and most timely. So that by the opening years of the last decade of the nineteenth century the architectural world had witnessed a revelation in construction probably never equalled in history—certainly not in a corresponding length of time.

In effect "cloud-scraping" buildings were manufactured in the steel mills, brick yards, cement factories, and terra-cotta works, transported piece-meal to the building site, and put together, each piece fitted into the exact place designed for it. Nor did the order in which these pieces were put together have to be followed in exact rotation in every instance. Foundation stones did not necessarily precede the masonry of the upper stories once the steel frame was up, as was necessary in the older form of construction. As the masonry of each story rested on steel supports it was now possible for the masons to begin, literally, at the top stories and build the walls of the upper stories first, or to work on the walls of several different stories at once. Indeed it was not an uncommon sight to see a tall building in the course of erection in which the masons were laying the walls of several stories simultaneously.

In these new buildings the modern architects had to meet certain conditions and solve certain problems that would have puzzled the builders of a century ago. Among these was the question of heating and fire-proofing. Elsewhere a description of this fire-proofing is given; the problem of heating was a relatively simple one, thanks to the application of steam and hot water.

THE PROBLEM OF HEATING

Like many other anomalies in the progress of civilization hot-water heating represents one of the oldest as well as the newest methods of heating buildings. At the very time when the ancient Greeks were heating their houses with open fires, the smoke from which made its exit through a hole in the roof like the fire in an Indian tepee—since the Greeks were not familiar with chimneys—their neighbors, the Romans, were



SKYSCRAPERS IN PROCESS OF CONSTRUCTION.

The steel frame-work in the center of the picture is the tower of the Singer Building, New York. The white-walled building in the foreground is the City Investing Building.

heating their rooms with hot-water pipes. Such heating pipes still exist in the ruins of Roman buildings.

Of course the hot-water heating system of the Romans was a crude and relatively simple affair. It fell into disuse after the Roman period until the latter part of the nineteenth century. Indeed for some centuries after the invention of chimneys and the accompanying fire-places, there was little progress in house-heating devices. Iron stoves, or receptacles for holding fire called by that name, were sometimes constructed for special purposes even as early as the fifteenth century; but these were not practical for general heating purposes, and the beginning of the era of modern house-heating dates from the invention of the "Franklin stove" by Benjamin Franklin in 1744. This stove was little more than a fire-place made of iron so that it would project to some extent into the room and thus make the heat from three sides available. A little later, when a short pipe was added, the fourth side was also utilized for heating. This stove was revolutionary in its effects as a fuel-saver and heat-giver. With an equal amount of fuel this stove would heat at least four times the space heated by a fire-place, and heat it more uniformly. When dampers and drafts had been added it became possible to control the fire in a manner never known before; and for the first time the world—particularly the American world, which adopted it at once—came to know the comfort of heated houses.

In the century following Franklin's invention so many improvements were made upon the original stove that the old type practically ceased to exist except in a much modified form. Meanwhile many adaptations of the stove to heating had been developed. Stove pipes had been lengthened so that it was no longer necessary to have the stove placed near the chimney, and long heat-conducting pipes had been added so that an entire building could be heated from a stove placed in the basement—the hot-air furnace, still a very popular form of heat distributor, particularly for small buildings.

A very marked improvement had been made, about the middle of the nineteenth century, in stoves constructed so as to burn anthracite coal—base burners, and magazine-feed stoves. These were soon on the market in all sizes, from tiny heaters for hall rooms to great furnaces for supplying heat to huge buildings. Steam, which had become the most universal source of power, had also been adapted to heating. The first building heated by steam in the United States was the Eastern Hotel, of Boston, in 1845; and in the same year one of the large woolen mills in Burlington, Vermont, established a similar system of heating. Hot-water heating, where water is made to circulate through pipes instead of steam, had also come into use. So that the skyscraper constructors did not lack facilities for heating their many-storied buildings, no matter how far skyward they pushed them. The great obstacle for many years, as has been said, was the lack of transportation facilities; but the introduction of swift-moving and reasonably safe passenger elevators removed the final obstacle. This device must now claim our attention.

THE ELEVATOR OR "LIFT"

It should not be understood that a mere hoisting device for elevating or lowering freight or passengers constitutes an "elevator" in the commonly accepted meaning of the word. The use of such machines antedates the Christian Era—is as old as the use of block-and-tackle itself. For centuries men have utilized such devices in one form or another for unloading ships, operating mines, and transferring goods to and from the upper floors of buildings. But these primitive machines, although having most of the essential points of the modern elevator, lacked the all-important one—the device for stopping the fall of the car in case of a break in the hoisting apparatus. Until such a device was conceived the old-time hoist remained much too dangerous a contrivance for passenger use except where absolutely necessary as in the case of mine shafts. But in 1853 Elisha G. Otis exhibited at the World's Fair in the Crystal Palace, New York, an elevator which, for the first time, had a safety device for stopping the fall of the car. Five years later the same inventor perfected a specially constructed steam engine for operating the machinery of such elevators, and the era of higher buildings was inaugurated.

For the first ten years after this invention practically the only power used for operating elevators was steam, and steam-propelled elevators are still used, although steadily declining in popularity. But the obvious disadvantage of such elevators in small buildings, such as private dwellings, where it is not practical to keep a steam-boiler going at all times, soon made inventors look about them for other kinds of power. The most obvious one, and incidentally the oldest, was hydraulic pressure; and early in the seventies "hydraulic water balance elevators" were introduced and for a time rivalled steam elevators in popularity.

The principle upon which these elevators worked was that of the balance, in which the heavier of two suspended weights caused the lighter one to rise. As applied to these elevators, an iron tank of water at one end of the hoisting cable acted as a weight for raising the cage at the other end of the cable. By means of valves water was admitted into the tank until its weight was greater than that of the loaded cage, the amount of water required depending upon the weight to be lifted. For lowering the cage the water was run out of the tank, allowing the cage to descend by its own weight, the speed being controlled by friction brakes.

Despite the popularity of such elevators they were expensive to install and maintain, and rather complicated, and a few years after their introduction were displaced by the horizontal hydraulic type of elevator invented by the English engineer, William Armstrong. This type of hydraulic elevator, and its modified vertical form, are used to-day in greater numbers than any other form, although electric elevators are rapidly overhauling them in popularity.

Unlike the "water balance elevator" the horizontal hydraulic elevator is dependent upon water pressure acting upon a piston in a closed cylinder. The power derived from this action is utilized in various ways to meet certain conditions. Thus the size and length of the cylinder are dependent upon the size of the elevator, the length of the elevator shaft, and the amount of water pressure available. Where economy of space is necessary, short cylinders are used, in which the water pressure may be seven or eight hundred pounds to the square inch. By connecting these with several sets of pulleys, or sheaves, even a very short cylinder may be made to propel elevators in high buildings. Or just the opposite conditions may prevail, long cylinders and pistons being used to operate through relatively long distances under low water pressure obtained from the ordinary city main. But in any case the hydraulic engine is single-acting in such elevators, the weight of the car being utilized for the descent.

A modification of this type of hydraulic elevator is the "pulling plunger" elevator, in which the weight of the piston is greater than the loaded car. In this type of elevator the water is expelled as the car ascends, driven out by the weight of the piston—just reversing the action of the ordinary hydraulic elevator—the water pressure being used to raise the piston and allow the car to descend.

There is still another class of hydraulic elevators, known as the plunger, or direct-lift class, which instead of being pulled upward by cables are pushed up from below by a steel piston acting directly against the base of the car. The length of this steel piston and the cylinder in which it works are the same as the elevator shaft and are set vertically in the ground beneath the car. Thus the cylinder of such an elevator working in a one-hundred foot elevator shaft reaches to a depth of one hundred feet under ground. The car is raised by water pressure in the cylinder, the water being expelled in the descent. Such elevators do away with sheaves and winding-drums, use cables only for counter-poise weight, and are entirely practical even in very high buildings in metropolitan districts.

In electrically operated elevators an electric motor takes the place of hydraulic pressure, being attached to suitable winding machinery, which operates the hoisting cables or plungers. Their advantage lies in the small space occupied by the power plant, and their speed and flexibility in operating place them in a class by themselves. Thus the "push button" control elevators, which are popular in private residences, are so simple in operation that literally the only mechanical skill required for operating is the ability to push a button. If a person wishes to ascend to the fifth floor, for example, he simply steps into the car, pushes the button marked "five" and the car ascends and stops at the proper landing. Should a person on any floor wish to call the car he simply pushes the call button and waits until the car arrives, which it does automatically, if not in use, stopping at the landing indicated. The door at this landing is also unlocked automatically, so that the passenger may step in and reach any other landing simply by pushing the button indicated.

SAFETY DEVICES

But after all, the various mechanisms for moving the elevator up and down are of minor importance from the passenger's point of view, when compared with the device for stopping the elevator in case of a breakage of the lifting apparatus. This was pointed out more than half a century ago by the first inventor of such a device and is just as true to-day.

An elevator is really a railroad with a grade of ninety degrees, but differing from the ordinary railroad in that the car slides along two rails instead of passing over them on wheels. The rails of the elevator, then, act only as guides for keeping the car in position except in case of accident, when they play an all-important part in stopping the descent of the car. Many such devices have been invented, but practically all of these fall into one of two classes—those designed to act upon wooden rails, and those that act upon metal. The safety devices which act upon wooden rails do so by gouging into the wood, and may be in the form of safety dogs, or chisel-like structures; while those that act upon metal rails are usually in the form of nippers that grip the rail on either side. Some of these are controlled by the action of springs which allow the safety device to act only when the car is moving faster than a certain rate of speed—in short when it is actually falling.

This type is used mostly on small elevators and is considered inferior to those that are controlled by some form of governor which remains inactive at normal speed; but when this speed is increased to twenty-five per cent. above normal they become instantly active, causing the powerful steel nippers to grip the guide rails with increasing pressure until the car is stopped. Obviously the action of these nippers must be rapid, since a falling body moves sixteen feet during the first second, and thrice that distance the next. But since the car must be descending at a fairly rapid rate before the safety clutches act at all, it is evident that if they acted instantaneously the passengers might receive a hard shock. They are arranged, therefore, so as to act gradually (relatively speaking, of course), their gripping force increasing evenly but steadily with every inch of descent. So that while the car is stopped quickly there is a graduated diminution in speed. In actual practice it has been found that the passengers seldom receive severe shocks when this system of safety clutch is used.

Considering the number of persons that are carried every day in elevators and the amazingly small percentage of accidents, the claim that the modern elevator is one of the most highly perfected mechanisms ever devised cannot be disputed.

The telephone plays an important part in relieving the elevator service of the modern office building. It is estimated that without telephone service the number of elevators required to handle the traffic in the ordinary skyscraper would consume so much space and so increase the cost of maintenance that the rentals for floor space would be prohibitive.

NEW TOOLS AND NEW METHODS

It is but a natural result of pressing demand that in developing the construction of the new steel-frame buildings new implements have been invented to facilitate the builder. To give a complete list of these without discrimination as to their novelty and importance is of course out of the question. On the other hand no story of the progress of modern architectural construction can approach completeness that fails to give full credit to the various implements worked by compressed air, and known as pneumatic tools. In European countries, where the cost of manual labor is relatively low, the time element does not enter so greatly into the cost of construction. In America, however, where wages are high, and in large cities where the values of land make every day that a building site remains idle a very material loss to the owner, rapid construction is a necessity.

It is to meet this demand that pneumatic tools with various other time-saving devices have come into prominence in recent years.

In these pneumatic machines no new principle is involved, as it is possible to obtain the rotary or reciprocal motions with steam quite as well as with compressed air. Indeed in factories where corresponding stationary machines are used, such machines are often driven by steam. But steam is too hot for portable hand-mechanisms; and one of the great advantages of pneumatic tools is that they can be made light enough so as to be carried to any part of a building, connected to the compressed-air tank by a rubber cable.

Every one who has been in the immediate vicinity of a modern steel-frame building in the course of construction is familiar with the sound, if not the mechanism, of the pneumatic hammer used for riveting. It is utterly impossible to escape it. The shrill br-r-r-r-r of the rapidly repeated strokes, striking against the metal rivet at the rate of 1,500 to 3,500 blows a minute, can hardly fail to attract attention. This pneumatic hammer may be taken as a typical representative of the class of percussion tools adapted to many other purposes besides that of riveting. It is about three inches in diameter and eighteen inches long, containing a cylinder in which works a piston with a back and forth action, driven by compressed air admitted and exhausted by suitable openings. For convenience in holding there is a handle at one end which is held by the operator, who presses the other end of the tool, which contains the rivet-set, against the red-hot rivet. He then presses the trigger-like throttle, admitting the compressed air, and holds the rapidly striking hammer in place until the riveting is completed—a matter of seconds only.

As some counter-pressure is necessary for holding the rivet in place, these hammers are frequently made with a U-shaped end, particularly for special work in factories. But since these are not practical when working in many places in steel-frame construction, the hammers for this purpose do not have the U-shaped end, as a rule, counter-pressure being made by a man holding a sledge against the end of the rivet opposite the riveter.

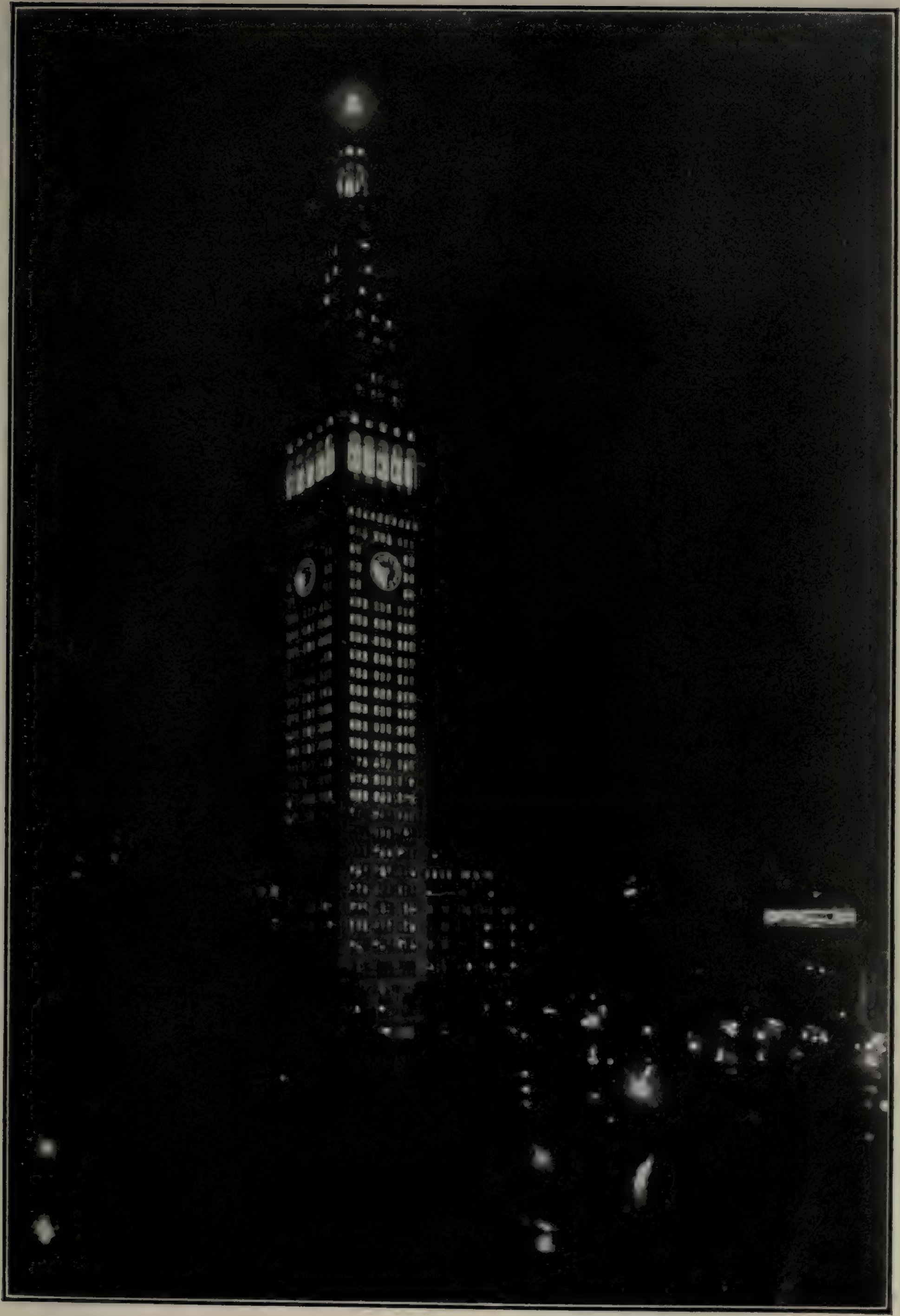
The efficiency of this hammer depends upon the number, rather than the force, of the blows struck, and may be utilized for many other purposes besides riveting, such as hammering and calking. Similar hammers are also used for chiselling, and have revolutionized stone carving, taking the place of the chisel and mallet of the old-time carver. Machines for this purpose give very light but rapid strokes—as high as 15,000 blows a ninute—so rapid indeed that the sound made is a continuous buzz in place of the rapid, interrupted tapping of the riveting hammer. The carved stone-work of the steel-frame buildings is often made with these tools after the roughly cut stone is in place on the building.

There are great numbers of pneumatic tools having a rotary motion adapted to various kinds of boring and drilling machines, both for wood and metal working. These are, of course, used in innumerable ways in building construction, although seen less frequently than such tools as the pneumatic riveter because their use is often confined to factories.

The modern steel-frame structures, perhaps the most beautiful examples of which are represented by American hotels and apartment houses, are frequently spoken of as "palaces." Save for the fact that they are not the residences of crowned heads, the term is not inappropriate. For many of them are quite as large, and far more magnificent in their appointments than most of the European palaces. In the matter of comforts and convenience the advantage lies entirely with the American structures. To be sure there are many European palaces in which an effort is made from time to time to keep up with the tide of progress by adding such improvements as modern elevators, and modern heating and lighting appliances. But at best these are only make-shifts—antique structures with new garnishings. And the American in his palatial residence, with every convenience for his comfort provided by engineer and architect, may well smile at the crude dwellings with ancient armorial bearings—crude at best, from the standpoint of comfort and convenience—built before the days of steel-frames, steam heating, and applied electricity.

SOME THOUGHT-PROVOCATIVE STATISTICS

The luxury of equipment of modern dwellings is equalled—often surpassed, indeed—in the buildings used for business purposes, particularly in New York which has the distinction of having the highest office buildings as well as the highest-priced real estate in the world. The fact that the land on which a narrow, twenty-story skyscraper stands sometimes costs more than the building itself gives some conception of these values. The most notable example of this is the Flatiron Building, the site for which cost $2,500,000. And yet this figure does not represent the acme of price per foot in the metropolis. This distinction goes to a little corner lot on Wall Street and Broadway, which



THE TOWER OF THE METROPOLITAN-LIFE BUILDING, NEW YORK, ILLUMINATED.

The top of the lantern is seven hundred feet above the street.

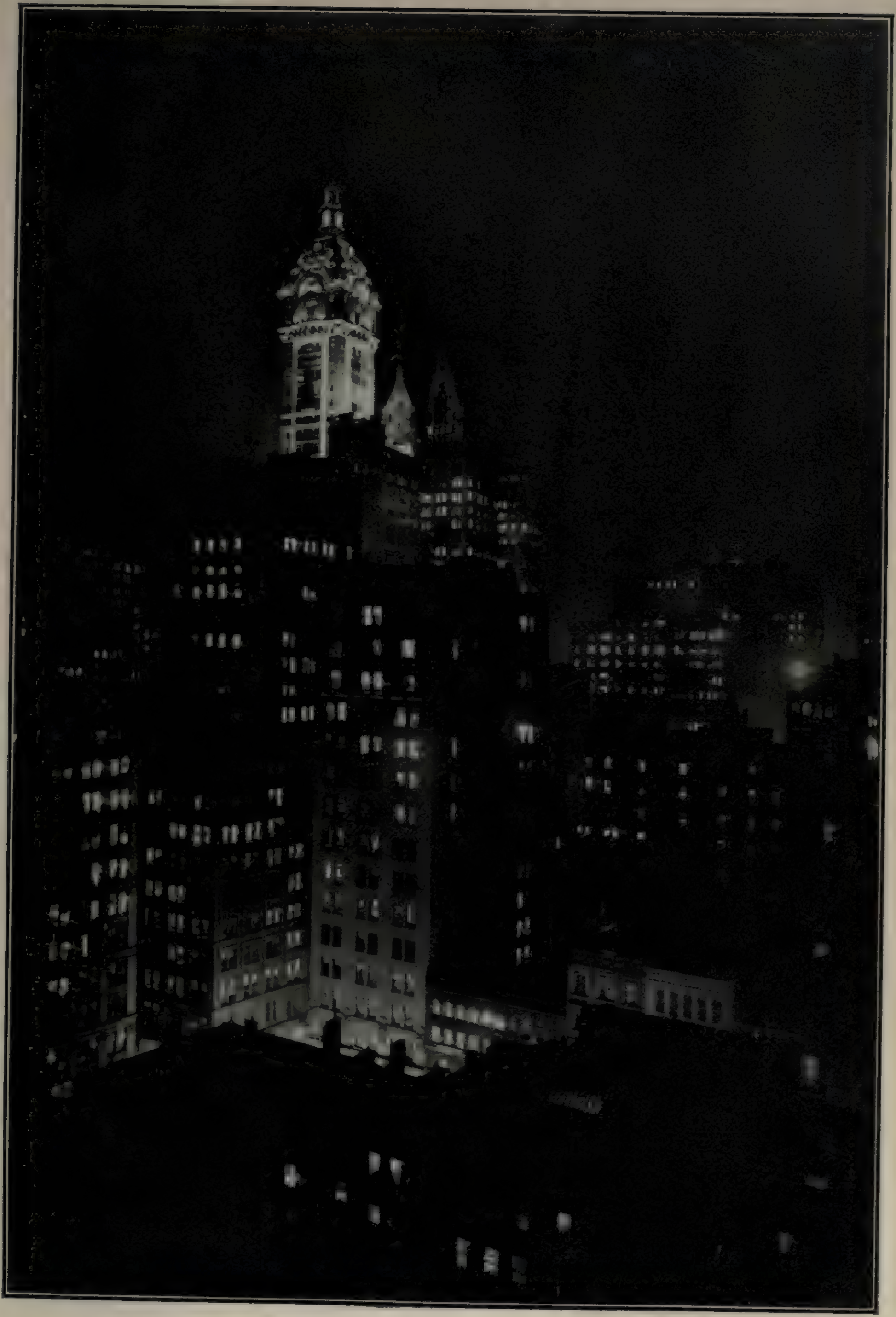
sold for $600 per square foot—the highest price ever paid for real estate anywhere in the world.

Thirty years ago a ten-story building represented about the limit of habitable structures. Ten years later there were buildings having twice that number of stories. To-day the fifty-story structure—the Metropolitan Life tower—is an accomplished fact. What is the limit to lofty construction? An answer to this question is found not in the matter of strength or weakness of the structures themselves, as Mr. O. F. Semsch who designed the steel work for the Singer tower has pointed out, but a clause in the Building Code, at least as regards the City of New York.

The Singer tower, the dome of which stands 612 feet above the sidewalk, measures only 65 feet on each side. Mr. Semsch finds that, even by keeping well within the restrictions of the Building Code, a building 2,000 feet high might be erected with safety on a lot 200 feet square. Such a building would have about 125 stories, would weigh over 500,000 tons, and cost about $60,000,000. The engineering problem to be met in constructing such a building assumes proportions quite beyond the grasp of the layman even if stated in plain figures. Those of the Singer tower, which has only one-twentieth of the weight of the hypothetical building in question, are sufficiently staggering.

Thus, "the wind pressure at 30 pounds per square foot exercises a total overturning moment on the whole tower of 128,000 foot-tons. Although the total weight of the tower is 23,000 tons, the wind pressure would have a tendency to lift the windward side of the building, the total uplift on a single column amounting, for maximum wind pressure, to 470 tons. To provide against this the columns are anchored to the caissons, and the margin of safety against lifting is in no case less than 50 tons to the column. The effect of the wind pressure on the leeward side of the building also affords some interesting figures. Thus, the total dead load at the foot of one of the leeward columns is 289.2 tons, which represents the weight of the steel work and masonry. The live load, which includes furniture, fittings, and the maximum crowd of occupants, totals, at the foot of this column, 131.6 tons. The downward pressure on the leeward side of the building due to wind pressure is 758.8 tons, and this, added to the dead and live loads, brings the total load on these columns up to 1,179.6 tons."

The Singer Building is neither the tallest nor the largest office building in the world, this distinction being held, for the moment at least, by the Metropolitan Building in New York. The tower of this building is 700 feet high, and the total floor space of the building is over 25 acres. A close second for size is the City Investing Building, thirty-three stories high, with a total floor space of 670,000 square feet, accommodating 6,000 people. Both these figures are surpassed by the combined sections of the Terminal Building whose basements are occupied by the terminal stations of the Hudson Companies' tunnels. But since these sections are separated by a street, and are not under a single roof, they cannot be considered as a single building.



A GROUP OF SKYSCRAPERS ON LOWER BROADWAY, NEW YORK.

The highest building near the center is the tower of the Singer Building. The next highest building, at the right, is the City Investing Building.

The question of the exclusion of light, rather than any insurmountable engineering problem, seems likely to limit the height of buildings in America, in the near future, as it does already in many European cities. Groups of tall buildings on narrow streets put the pavement in a constant state of gloom even on bright days. It is probable, therefore, that the height of the building on a street will be limited by the street's width, or the distance from the street at which the highest stories rise.

VIII

ARTIFICIAL STONE, OR CONCRETE

THE Greeks and Romans were not the only ancient people who had learned to use some kind of cement as a substitute for rock in building. The Mexicans in the Western hemisphere are known to have used it extensively in some of their constructions. But none of these cements had exactly the composition of the modern Portland cements, whose superiority makes possible the wonderful present-day building operations. The endurance of the dome of the Pantheon through two thousand years would seem to disprove any contention that Roman concrete needed anything in the way of improvement. Yet it is undoubtedly true that Portland cement is far superior to the Roman "puzzolana," as it is called, for most purposes. It has greater resistance to crushing, and is not affected to so great an extent by oxidation in a dry atmosphere.

Through the action of volcanoes, Nature placed material for cement in the very dooryard of the Romans. The volcanic dust found near the village of Pozzuoli, when added to lime could be transformed into a cement which would set under water, and be as enduring as rock itself. The Romans called this cement puzzuolani, but this has been shortened to puzzolana, as the modern name for any cement made of volcanic dust, or powdered burnt clay, mixed with powdered hydrates of lime. It is much lighter in weight than true Portland cement, and is of a light-lilac color, rather than the familiar bluish-gray of the modern cement. At the present time its use is limited to structures that are exposed to a moist atmosphere, or those under water.

The manufacture of Portland cement, which gets its name from its resemblance to the famous Portland building-stone of England, began in the early years of the nineteenth century. It is produced by calcining a mixture of calcareous and argillaceous substances, and grinding the resulting clinker to extreme fineness. When this is thoroughly mixed with certain proportions of sand, gravel, or broken rock, and thoroughly moistened, it sets into an apparently homogeneous rock, of a quality superior to most building-stone, and less expensive. Its great flexibility in working, along with its other remarkable qualities, make it the favorite medium of modern construction. It can be cast in molds as bricks or building-stone, which may then be laid in mortar; or the molds can be so arranged that an entire wall, or even a building, may be cast, the whole structure being as homogeneous as if hewn from solid rock. If steel rods are laid in the concrete during the course of construction—making "reinforced concrete," to which we shall refer a little later—the resulting building will be stronger and more enduring than if hewn out of granite itself.

CONCRETE BLOCKS

Since the dawn of history, the most popular form of building material which could claim any great degree of permanency, has been in the form of small units of uniform size, such as bricks. The reason for this is obvious. The convenience in handling such units, and the varied forms of structures that could be fashioned with them without very great difficulty, insured such popularity. The cheapness of bricks, and the fact that clay for making them is found in practically every part of the world, has added to this popularity. Until some substance could be found that competed in all these good qualities, and could show some superior ones, the preeminence of brick as building material remained unassailed. It was not until the closing years of the nineteenth century that any substance made a permanent bid for this position—not until the concrete block was perfected, that the position of the brick was seriously jeopardized.

First of all, the predominating advantage of price had to be met. But there is another item besides the one of actual manufacture that has to be reckoned with in brick-walled structures. This is the cost of construction. The smaller the units the greater the cost of building them into a permanent structure. And here the concrete block scored a point over brick. There is a limit to the size at which the brick can be made economically. There is practically no such limit to the concrete block. Besides this, the concrete block is stronger and more resistant to moisture, atmospheric conditions, and fire. These qualities, together with the flexibility of concrete as a working medium, give concrete blocks the position they now hold as building material.

Although the concrete block, when finished, has such remarkable qualities, there is nothing complex or extraordinary in the process of its manufacture. Any person with reasonable intelligence, a little knowledge, and sufficient industry to see that the component materials are well mixed, can make a first class article of concrete. The exact proportions of the materials are less essential than the thorough mixing of them. Thus, one part Portland cement, two parts of sand, and four parts of gravel, or broken rock, when thoroughly mixed with water, will set into a good concrete block; the more thorough the mixing the better the block. The exact amount of the hard substances, and the amount of water used, may be varied within wide limits; but there is no deviation from the cardinal rule of thorough mixing. "Ultimate success with any mixture," says one writer, "can only be obtained by the entire coating of every grain of sand with cement, and every piece of stone or gravel with sand-cement mortar. . . . Only by this method can voids be eliminated and the greatest strength obtained. There are, however, other advantages resulting from an absence of porosity. The permeability of a concrete block is greatly reduced by added density, and with sufficient attention to this matter the question of waterproofing is, at least in a measure, solved. Efflorescence is also practically overcome by making really dense and reasonably impervious blocks."

Generally speaking, the greater the proportion of Portland cement used, the less will be the porosity of the concrete block. For it is the minute particles of the finely powdered cement that act in filling up the voids between the larger particles in the aggregate. To get a clear idea as to the amount of space left between the individual particles in a heap of gravel whose units approach the spherical in shape, a pile of perfectly spherical cannon-balls of the same size may be considered. In such a pile the spaces left amount to some twenty-six per cent. of the entire mass. If these spaces were fitted with smaller balls just large enough to touch snugly all points of contact without displacing the larger balls, the voids would be reduced to about twenty per cent. Smaller and smaller balls could be added (theoretically, at least) until all the air spaces had been filled to such an extent that the mass would be impermeable to water. To do this the smallest particles would necessarily be of a fineness corresponding to those of an "impalpable" powder.

In comparing this mass of perfectly spherical balls to the substances composing the mass of concrete, the Portland cement represents the finest particles, and the ones that give the mass its adhesive quality; the intermediate-sized balls are represented by the sand; and the largest balls by the particles of gravel or crushed stone. The comparison holds only in the matter of the filled air-spaces, however, for even the finest shot has none of the adhesive qualities of the particles of cement.

MIXING THE MATERIALS

Since thorough mixing is so essential in making blocks, or in building with concrete on a large scale, steam-driven mixers are used which produce an enormous quantity of concrete of uniform consistency, although hand-mixing is still in general use in any but the largest operations. Machine-mixed concrete is usually of greater strength than that made by hand, and is likely to be more uniform in color, as the amount of water used in each batch can be better regulated. The exact shade of the finished block, when the proportions of the solid substances are the same, depends to a great extent upon the amount of water used.

Mixing by hand is usually done on a board platform. The sand to be used is spread upon the platform and the dry cement spread over this, the substances being mixed thoroughly by turning with a shovel before being moistened. Water is then sprayed upon the mixture, which is stirred constantly. When thoroughly moistened, the gravel or broken stone is added, the mass turned repeatedly, until ready for the block molds.

Mechanical mixers are made in a variety of shapes and on many different principles. Some of the larger ones in use on extensive building operations are continuous producers, a steady stream of concrete emerging from one end of the machine, while the cement, sand, gravel, and water are poured continuously into the feeding-end in the required proportions. Owing to the difficulty in measuring the various substances accurately, many builders prefer "batch-mixers," which have to be filled and emptied successively. The general principle upon which all these machines work is that of the time-honored churn, the contents of which are jostled about in every direction. Some of the mixers are barrel-shaped, having fixed paddles in the interior which stir the contents thoroughly when the surrounding cylinder is revolved. Others are box-shaped, the angles of the box performing the same functions as the paddles when the machine is rotated. Still others are in the shape of a long trough with a longitudinal shaft upon which are placed several propeller-like blades running through the center. Material thrown into the upper end of this machine is thoroughly mixed by the time it reaches the other end, so that they are adapted for use as continuous, or batch-machines, as the operator may prefer. A very simple type of mixer is one in which the action of gravity is utilized. This is in the form of an upright tube, or box, along the inner surface of which projecting obstructions are placed at intervals. The material is thrown in at the top and, striking against the obstructions as it descends, is jostled about until it emerges from the lower end of the tube mixed perfectly.

With all these machines great difficulty lies in feeding them with the various materials in the correct proportions. Mechanical measurers have been perfected that do this accurately and satisfactorily, but such machines are too expensive for most builders. The usual method of feeding the mixers is by shoveling —obviously one that is likely to be very inaccurate. Some ingenious contractors, however, find a way of using shovels as very accurate measurers. If the mixture they wish to use consists of one part cement, two parts sand, and three parts gravel, they place three shovelers at the gravel pile, two at the sand pile, and one at the cement pile, each supplied with shovels of exactly the same size, so made that they will take up practically the same amount of material at each scoop of an average workman. By having these six men shovel in unison they are able to supply the mixing machine with the materials in proportions accurate enough for all practical purposes.

MOLDING THE BLOCKS

For molding the concrete into blocks, mixtures of three consistencies are used, known as dry, medium, and wet mixtures respectively. The dry mixture is not dry in the strict sense, but is of a consistency too stiff to be poured; the wet is thin and pours readily; while the medium is intermediate between the two. The molds used may be of any desired size or shape, and are sometimes made of sand in much the same manner as molds for iron-casting. More frequently they are made of iron or wood, so arranged that the sides are jointed to facilitate the removal of the block when it has set.

When a dry mixture is used, this is shoveled into the mold and tamped into place as the mold is filling. A block made in this way sets quickly and may be removed from the mold in a short time, so that fewer duplicate molds are required than when a mixture containing more moisture is used.

When blocks are made by "pressing," a medium mixture is used, wet enough so that the water flushes to the surface when slight pressure is applied. This is poured into the molds and pressure applied over the entire surface, all portions of the block being compressed equally at the same time. The advocates of this method claim for it the advantage of producing blocks of more uniform density than by other methods.

When blocks are made by the "pouring method," the cement is reduced to a fluid state, poured into the molds, and allowed to set. As the setting requires some little time there is a gradual settling to the bottom of the heavier particles of the mixture, so that the block will not be of uniform density throughout. Another, and more serious objection to this method from the manufacturer's point of view, is the fact that so many more molds are required, owing to the slow process of setting. At the same time the great flexibility of the wet medium makes it a favorite one for certain purposes, while the fact that an excess of water has been used makes it unnecessary to pass the blocks through the subsequent "curing" process, to which blocks made by the dry process must be subjected if they are to be of first-class quality. For strength and durability can only be secured by the presence of sufficient water to produce the chemical reactions resulting in the crystallization of the silicates of aluminum and lime.

This curing process is the most tedious of all those involved in concrete-block construction, and unfortunately, the one that is most likely to be slighted. Blocks made by the dry process must be cured by repeated sprayings with water for a period of from ten to twenty days, during which time they should not be allowed to become dry; and blocks made of medium concrete require a proportionate time for the curing. For the chemical process which results in fine concrete is a slow one, unless hurried by heating, or some other expensive process. It is a strong temptation to the block-maker, therefore, when his customers are chafing at what must seem needless delay, to curtail the curing process. Blocks so slighted may have every appearance of being first class, and only the crumblings wrought by the atmosphere a few years later reveal the folly of the block-maker. Folly, I say, as well as culpable negligence, since it is this and similar short-sighted actions on the part of the concrete-block maker in the past that have shaken the confidence of builders, and retarded the general introduction of concrete blocks as building material. Had honesty in the use of material, and care in the process of block manufacture been exercised in the past, the concrete-block industry would long since have assumed the enormous proportions that the usefulness of this material merits. It is just now coming into its own, through the efforts of manufacturers who have proved their claim to honesty.

Makers of furniture discovered, centuries ago, the art of veneering—a process of facing a piece of furniture made of cheap wood with a thin covering of expensive wood, so that the finished piece would have every appearance of a piece made throughout of the expensive wood. A similar process is used by concrete-block makers, of facing their blocks made of coarse, porous material, with an outer layer of fine, damp-proof concrete, colored "to suit the taste." The difference between this facing of concrete blocks, and veneered wood, lies in the fact that the facing of the concrete block becomes an integral part of the block itself, and is not simply a part fastened on by a different medium, such as the glue that holds the veneer to the wood beneath. Neither is it necessary that the material used in the body of the block be inferior in the essential qualities of strength and durability, but only in cost, appearance, and permeability, all of which may be corrected by the facing. A concrete made with a relatively low percentage of cement and a high percentage of sand and broken rock may be made strong enough and durable enough for even the most exacting purposes. It will lack the beauty and the moisture-resisting qualities of the finer article, but will have an enormous advantage in cheapness. In most places where concrete is used, the artistic appearance, and porosity, need not be considered; but in such positions as the fronts of buildings both these qualities are essential. To make the entire thickness of the block of high-percentage mixture ("fat mixtures," they are called), where special grades of sand, and expensive coloring-matter, as well as expensive cement, are used, would make the cost prohibitory. But by "facing" his block, the manufacturer is able to produce, without sacrificing quality, an article at a nominal cost, which has a beautiful appearance, and a dense and impervious surface.

Sometimes a coating of plaster is laid over the finished cement surface, just as plaster is applied over bricks or inside walls. But such troweled surfaces have a tendency to crack and disintegrate, and are distinctly inferior to faced concrete blocks, when the outer surface is molded at the same time, and is of similar material to the body of the block itself. The mixture for the facing is made at the same time as that for the body. If the bottom of the mold is to represent the face of the block a layer of the facing material is first placed in the mold and the coarser mixture added after. It is a common practice among the manufacturers to make the facing mixture a little dryer than that used in the body; but by capillary attraction the moisture of the block becomes evenly distributed throughout, and the concrete sets into a block quite as homogeneous as if a single mixture were used.

UTILITY AND BEAUTY

The advantage of such a block over brick or stone is obvious. A material that can be made into any size or shape, and of any color, which sets into a substance more resistant and enduring than most rock, at a cost considerably less than any permanent material furnished by Nature, does not have to go begging for advocates and champions in this practical age. Nor will its future in the artistic world be questioned by anyone who has seen some of the fine examples of concrete-block architecture that have been erected in recent years. One of the best examples is the Royal Bank of Canada in Havana, Cuba. This building is situated on one of the narrow streets of the Cuban metropolis, surrounded by the substantial but unattractive buildings scattered everywhere throughout Spanish America. Few people indeed suspect that this stately building, whose massive blocks seem to typify sturdy England, is not made of blocks of hewn stone. Yet its fluted columns at either side of the great arched entrance, its decorative cornice, and every pleasing artistic bit from foundation to roof have been cast of concrete in molds made of sand.

One of the greatest advantages that concrete-block construction has over every other form of masonry lies in the fact that it is so eminently adapted to "hollow-wall" construction, without sacrifice of strength or space, and with great saving of material. For this purpose the blocks are made hollow in their vertical diameter. The particular shape of this hollow space with its surrounding shell of concrete is the basis of many patents, and much ingenuity has been expended in producing easily workable designs which can be laid up quickly into walls. It is necessary that the inner and outer surfaces of such blocks shall form flat walls; but there seems to be no limit to the skeleton work of the interior of the blocks, so arranged that the walls will hold together, leaving an intervening air space. At the necessary points of contact some of these blocks are made with a layer of waterproof composition, such as a mixture of cement, sand, and hydrated lime, which is inserted during the process of making the block in the same manner as the process of facing. Buildings constructed of this form of block will be strong as well as damp-proof.

REINFORCED CONCRETE CONSTRUCTION

We have seen that concrete, made into blocks and laid up as the walls of buildings, forms an ideal fireproof material. Without some strengthening material, however, such as a steel frame, it is open to the same objections as stone or bricks for very high structures; but the modern skyscraper is an example of what can be done with it in combination. This same skyscraper, if built first of a skeleton of steel girders, and filled in with brick or stone afterward, has many defects. The steel in the structure has a different rate of expansion from that of the walls, causing collapses and catastrophes in conflagrations. For this reason the fireproof skyscraper is almost as much feared by firemen when its contents are burning as the older forms of building, although the walls cannot actually be burned.

But perhaps the greatest enemy of the steel-frame building is rust. Unprotected steel is a very perishable material, as building materials go. And while, in the course of construction, many precautions are taken to see that this steel frame is protected at every point, there is always a possibility that some joint or crevice will be overlooked and left exposed. Even the smallest crack that would admit moisture might, in time, be the undoing of the strongest steel structure, since the strength of the skyscraper lies in its steel frame. This possibility, among other things, has made the builder look to other materials as possible substitutes for steel; or for a permanent preservative that might be applied to the surface of the metal.

Paint is a very good preservative, although in order to give perfect protection it must be applied to the steel at comparatively frequent intervals. This is perfectly practical in such structures as bridges where the metal is exposed, but is out of the question in steel-frame buildings. And so the constructor of such a building must have a haunting fear that his most dreaded enemy may be gnawing insidiously into the very vitals of his structure, without giving him a chance to protect himself, or to detect the attack.

In looking about for some permanent protective for steel, it was discovered, curiously enough, that moistened Portland cement, or "fat" concrete, answered this purpose almost perfectly. Steel embedded in concrete will outlast the centuries. What could be more natural, or more ideal, therefore, than to combine these two substances as building materials? The experiment was tried, and the era of "reinforced concrete," or "concrete steel," as some enthusiasts call it, was inaugurated—an era which seems likely to prove the greatest the world has ever seen. For reinforced-concrete structures have now proved their claim to permanency against the attacks of cyclones, fires, and earthquakes, and have stood the ordeal better than any other class of buildings ever constructed.

Reinforced concrete seems to have been first used extensively by a French gardener named Joseph Monier, who had made great pots for shrubs of metal and concrete as early as 1867. Another Frenchman, and an Englishman, had made some experiments and demonstrations with the same material a few years earlier, but had turned their discoveries to little practical account. Monier patented his system, and it came into use quite extensively for making floors, tanks, ponds, and such simple structures; but it was a full quarter of a century before the subject of reinforcing had been studied sufficiently to be thoroughly understood, with guiding principles based on scientific deductions, in place of the mere rule of thumb used by Monier and the early builders.

ADVANTAGES OF REINFORCED CONCRETE

The first advantage of reinforced concrete as a building material that appeals to an American is its fire-resisting quality. The great Baltimore fire demonstrated that even where the heat was very intense the concrete was only affected to a maximum depth of three-quarters of an inch. Steel rods buried to a depth of one inch in concrete seemed to be protected perfectly. Even the sudden cooling by the streams of water caused very little disintegration, although such cooling is disastrous to unprotected steel work, or plain concrete. For concrete is a poor conductor of heat, and the rate of expansion of iron and concrete under the action of heat is practically the same. As a result, reinforced-concrete buildings are habitable almost immediately after a conflagration. During the conflagration the temperature of rooms adjoining those actually in flame is usually low enough for the firemen to work in without inconvenience or danger. The exalted opinion of reinforced-concrete buildings held by the professional fire-fighter is a significant tribute to this kind of building material.

Many interesting experiments have been made to test the protection afforded metal when embedded in concrete. These all seem to show that such protection is all but absolute; and this has been confirmed by a discovery, made by Von Empergner, of rods that had been embedded in concrete under water for some four hundred years and showed no signs of rust.

In embedding the rods no special precaution is necessary for their preservation save that of making certain that every portion is surrounded by the concrete. Even if the iron is somewhat rusty no harm seems to come from it. Indeed a little rust appears to aid rather than interfere with the preserving. "It is sometimes stated," says Marsh, "that the metal must be thoroughly clean before being embedded in the concrete, but this does not appear to be borne out by facts. In some tests made to elucidate this point, the curious fact presented itself that not only does rusty iron become clean when embedded in concrete, but that it becomes more effectively protected against oxidation than clean iron which has been similarly treated. A rusty nail and a clean nail were both embedded in the same concrete block and left for over three years; on being taken out the rusted nail had become free from rust. Both nails, together with a new nail, were then placed in water; the new nail rapidly became rusted. The nail which was rusty when first embedded in the concrete block showed no signs of rust a month after being placed in the water, except at one place, where it had been scraped with a penknife before being immersed; the other nail, after resisting the action of the water for a few days, showed signs of rusting, which increased with time."

Very early in the history of the development of reinforced concrete experimenters considered the possibility of utilizing this material in place of iron for the drainage pipes and water-supply systems of buildings. Ordinary concrete, made with a high percentage of the coarser materials, such as gravel or broken rock, does not resist penetration by water under high pressure sufficiently for this purpose. But by using a higher percentage of cement and fine sand, the concrete becomes sufficiently resistant to penetration for all ordinary purposes; and by adding a little soft soap and alum to such concrete it can be made absolutely impermeable without affecting its strength. The proportions used for this purpose are about two pounds of soap and twelve pounds of alum to every cubic yard of concrete mortar. This may be used as a thin facing-layer on ordinary concrete, as even such thin layers are impermeable, and are not affected by running water. A system of conduits made of this material has advantages over one made of iron aside from that of permanency, one feature being the avoidance of nodules commonly formed in iron pipes.

In 1886 the city of Grenoble, France, laid about a hundred yards of reinforced-concrete water-pipes in the regular system of water-works. Fifteen years later an examination of these pipes was made.

"The pipes have at all times resisted, and still resist, the normal pressure of 80 ft. head of water," says the official report. "The length of each section of pipe is 6 ft. 3 in., its thickness, 1⅝ in., and its internal diameter, 12 in.

"The metal skeleton of these pipes is formed by thirty longitudinal rods ¼ in. diameter and by an internal 5-32 in. spiral wire, also an external ¼ in. spiral wire.

"The sections of pipes weigh 88 lbs. each. They are connected together with reinforced-concrete rings.

"On February 2, 1901, a length of 16 ft. of these pipes was raised. Two of the joint rings were broken so as to free two lengths of pipe which had been lying under three feet of ballast.

"A close examination of these pieces established the following facts:—

"1. The irreproachable state of preservation of the pipes, in which there was found a slight calcareous deposit about 1-16 in. thick. They did no show the least fissure, either internally or externally.

"2. There existed no trace of oxidation from the metal. The binding-in wire which connected the longitudinal rods was absolutely free from oxidation.

"3. The adherence between the metal and the cement concrete constituting the body of the pipe was such that, despite the thinness of the concrete (1⅜ in.), they could only be separated by heavy blows from a sledge-hammer.

"4. When struck with the hammer, these pipes evinced remarkable sonority, such as might be obtained from a sound cast-iron pipe.

"5. The detached fragments of the cement concrete showed very sharp angles.

"6. The Water Committee of the City Council declared that this line of pipes had required no repairs since it was set in place in 1886."

From these, and similar exhaustive tests, it appears that reinforced-concrete pipes are ideal for drainage purposes, and are likely to replace iron ones in many places in structures where the pipes are built into the walls. In Thomas Edison's "one-piece concrete house" most of the piping of all kinds is of concrete. This material should not, however, be used for hot-water conveyors.

STRENGTH AND DURABILITY OF CONCRETE

Frameworks of steel or iron are lighter than those made of reinforced concrete for supporting the same load. This greater weight of the concrete is an advantage in most places, but not so wherever long spans are required, such as in bridges. For short bridges, however, it may be used in something the same manner as is steel, although the strains are arranged so as to be taken up differently. The "girders" of such bridges of the more recent types, seem scarcely larger than those used in many of the older types of iron bridges; while the abutments and retaining walls are much lighter than those built of masonry. It is evident that if, in this infant stage of reinforced concrete, such remarkable structures can be erected, there is little that may not be accomplished with it architecturally in the future.

The few reinforced-concrete buildings in and about San Francisco at the time of the earthquake demonstrated conclusively that this material resisted shock better than any other combination of materials used in construction. The effect of the shocks upon one building in the course of construction, which was being built of reinforced concrete in every part except the outer walls, which the building authorities had insisted upon having made of brick, was peculiarly instructive. The inner walls and supports were not affected, while the exterior brick walls were so badly cracked that they had to be replaced. Another striking demonstration was the effect of the shocks upon the Museum building of Leland Stanford University at Palo Alto, where the earthquake was very severe. The central portion of this building was built of reinforced concrete, while the two side wings were of brick, with brickwork floors. These two side wings were destroyed, while the concrete central portion of the building sustained only a few small cracks in the interior.

These practical demonstrations of the resistance of concrete to shock only served to confirm the experiments of engineers made on a small scale but along similar lines. One of these experiments, undertaken by some French railway engineers, was made by dropping weights from a given height upon reinforced-concrete floors, and comparing the vibrations produced with the effects upon floors made of iron and brick. The floors in each instance were built with the same bearing, and calculated to sustain the same load. When a weight of one hundred and twelve pounds was dropped from a height of six and one-half feet upon the brick floor, vibrations of five-sixteenths of an inch amplitude, lasting two seconds, were produced. But a weight twice as heavy, falling twice the distance upon the concrete floor, caused vibrations of only one-sixteenth of an inch amplitude, lasting only five-sevenths of a second. This shows conclusively that for resisting the shocks of locomotives passing over bridges, or the pounding of projectiles in warfare, reinforced concrete is superior to masonry. In practice it is rapidly replacing it.

In view of the fact that concrete is so relatively brittle a material it was thought for a time that reinforced-concrete buildings, and structures subjected to severe strains, might collapse suddenly when overloaded, without giving any warning such as is given by steel-frame buildings. Exhaustive experiments have proved, however, that such is not the case; that there is bending and sagging in reinforced-concrete bars before the final breaking. A beam calculated to support a load of four tons was loaded with thirty-four tons of iron rails as an experiment by a French engineer. Under this load four cracks appeared, and there was a slight sagging at the center. As the beam did not break, the load of rails was left in place. At the end of eight years no more cracks had appeared; and at last accounts the beam was still supporting its load.

THE REINFORCING SKELETON OF METAL

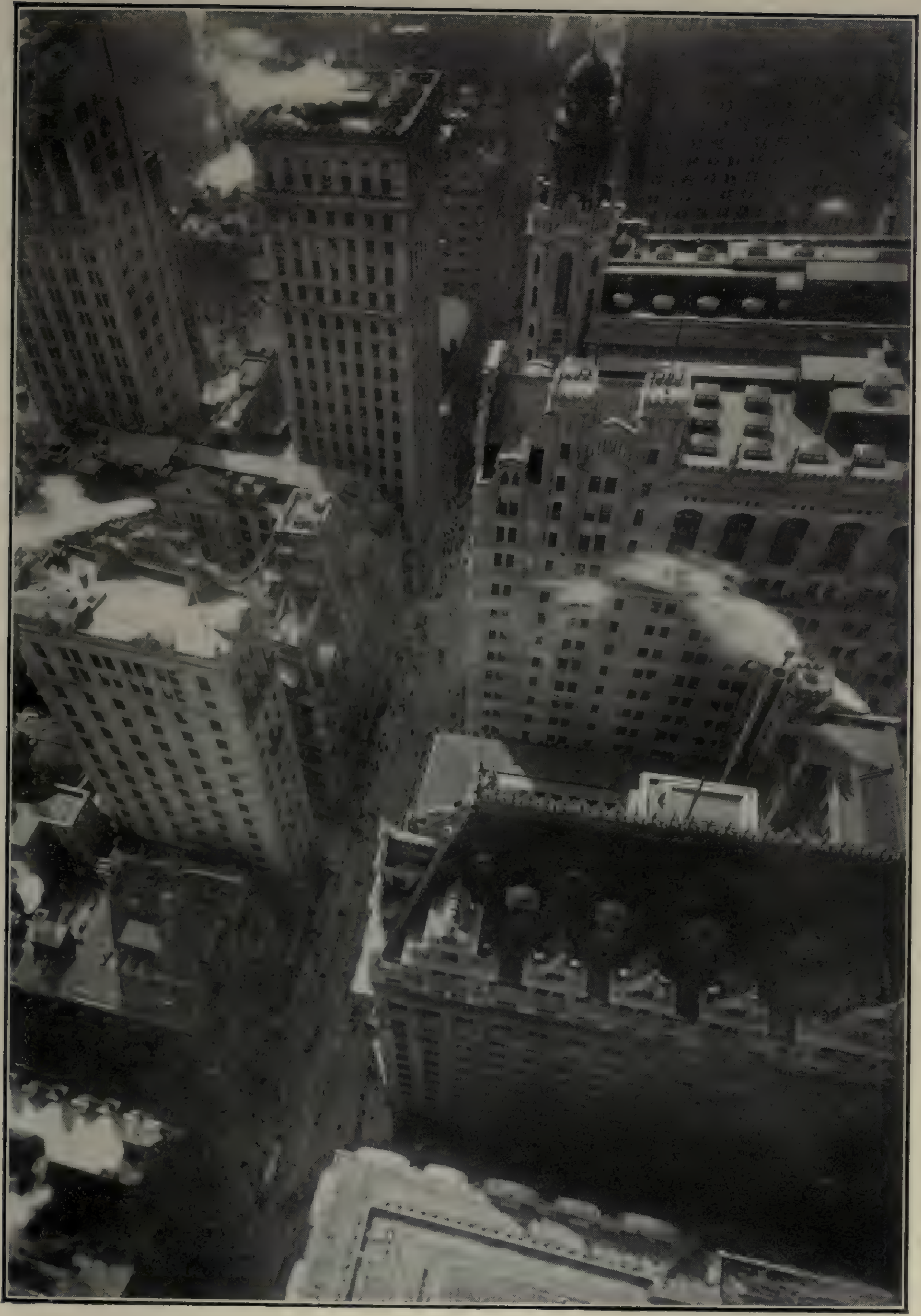
When it comes to determining the exact form of metal reinforcement best calculated to strengthen concrete, it is evident, from the numerous systems which have been evolved, that no single one is preeminently superior, but that there are a great number which are perfectly practical. Almost every engineer seems to have evolved a system of his own, more or less carefully studied out along practical, scientific lines. Some of these are simply longitudinal and transverse rods of the simplest arrangement, while others are complicated networks of steel bars and wires. It is the aim of every system to use the smallest possible amount of metal to obtain a given strength; and the amazing thing to the layman is how little metal is required for this purpose, where every strain, even of the smallest wires, is accurately calculated, and placed to the best advantage. Since the greatest strength of concrete lies in resisting compression, it is obvious that the reinforcement of upright columns require less metal strengthening than horizontal ones, and must have this reinforcement differently placed. Everything else being equal, each angle requires a different amount of metal, differently placed, to secure the same resistance; but this is an engineering problem too complicated to be considered here at length.

As the metal work is all completely buried in the cement in the finished structure, there is no way of determining by casual observation what form of reinforcement may have been used in any particular building. The exposed surfaces appear the same whether the reinforcement is a network of fine wires, or heavy "I" beams, and if properly constructed there is no difference in strength and durability. Some idea of how certain forms of reinforcement would look if concrete were transparent may be had from the appearance of "wire-glass,"—"reinforced glass" it could be called appropriately—which has become so popular in recent years. In this the mesh of wire can be seen embedded in the glass, the percentage of space occupied by the wire as compared with the amount of glass being very small. This same kind of reinforcement is used extensively in certain kinds of reinforced-concrete construction, but the size of the wire, and the resulting meshes are larger, although the proportions are not unlike those in wire-glass.

A MODERN BUILDING

Since there are so many different ways of using the reinforcement in concrete construction, perhaps a better way to gain a fairly clear idea of the subject, the size of the metal rods used, and the actual process of constructing a building, would be to study in detail the construction of one building, rather than the casual observation of all the different systems. For even meager descriptions of each of the different systems in use would more than fill an entire volume the size of this one. A typical structure for this purpose would be one of the new hotels recently constructed at Atlantic City, such as the *Traymore*, erected in the early months of 1907. A striking thing in the construction of this building, in which very little wood is found in the finished structure, is the fact that it was built very largely by skilled carpenters working at their trade. There is nothing surprising in this to anyone familiar with the process of reinforced-concrete construction. But what carpenter a quarter of a century ago would have believed that the introduction of fireproof stone and steel buildings would have increased the demand for members of his craft? It is simply another instance showing how difficult it is for anyone to visualize the effect that any innovation in the field of labor will have upon the workmen themselves.

It is a fact, of course, that any innovation in any field of industry which is a sufficient departure from existing methods of procedure in that field, must inevitably affect certain classes of workmen very materially. The increase in number of new classes of workmen must cause a corresponding decline in the numbers of the older class who can find work; and if the innovation be completely revolutionary in character the workmen of the older method must eventually become extinct. Many such revolutions have taken place in



HOW THE WORLD BELOW LOOKS FROM A SKYSCRAPER.

A view of Broadway from the tower of the Singer Building, New York.

the industrial world, and while most of them have been effected so gradually that they have caused comparatively little hardship to the skilled workmen, it has happened more than once that some have been so sudden in their results, owing to the marked superiority of the new methods, that much suffering has been caused among certain classes of workmen. In our own generation a most striking example of this is shown in the field of wood-engraving. The introduction of photographic methods, superior, quicker, and far less expensive than hand methods, captured the world so quickly that thousands of skilled wood-engravers were thrown out of employment permanently. In this particular instance great hardship was caused to a certain class for the benefit of the world at large.

It is the possibility of this sort of thing that causes many classes of skilled workmen to oppose threatening innovations. A century ago such new methods were combated violently in many instances. This was at the beginning of the age of machinery, when it appeared to many that manual labor, particularly skilled labor, was doomed. The inventors of the cotton gin and the power-loom, for example, had literally to fight their way through armed mobs to place their machines in the factories. Yet the members of the mobs found, after they had lost their bloody contests, that the very machines they had opposed gave them more work and better pay than the older systems they had fought to uphold. These are but two examples, out of hundreds that could be cited as showing how little anyone can predict with certainty just what effect upon manual labor the introduction of any labor-saving machine may have.

The introduction of steel-frame construction menaced the business of the carpenters. But steel-framed buildings are comparatively few. A more serious menace seemed to be the introduction of concrete construction, which was not confined to towering city skyscrapers, but became popular in the construction of smaller buildings of all kinds. Yet, curiously enough, this very form of construction is dependent upon the work of the carpenter, as we shall see from the description of the construction of the *Traymore Hotel*, referred to a moment ago.

This building, nine stories high, covering a space one hundred and twenty-two feet long by seventy-six deep, was erected and completed exteriorly in exactly three months and five days. The nine stories do not include a massive dome, in which there are three additional stories. The foundation for the concrete was made of piles driven down below the water level with their caps bedded in concrete. The supporting pillars of reinforced concrete varied in size from square columns twenty-four inches, and octagonal ones with minimum diameters of twenty-eight inches, at the lower story, to columns ten inches in diameter in the upper story. These were reinforced with eight ¾-inch steel rods for each column, placed in the angles and in the middles of the square columns, and in the middles of the flat surfaces in the octagonal ones. So that the actual surface of steel in the larger columns was only a little over one one-hundredth of the concrete surface.

These steel rods in the square columns were connected horizontally by ties one and a half by three inches, placed ten inches apart, while those in the octagonal columns were wound spirally with quarter-inch wire rods, having a pitch of three inches. "The wall columns are virtually rectangular piers," says the *Scientific American*, "and, like the interior columns, their dimensions increase from the top downward until in the basement a maximum of twenty-six inches square is attained. Beams and girders are made in the standard manner, reinforced with Kahn tension-rods (rods with projections at intervals) in the lower sides which project nearly through the supporting columns. Additional bars about six feet long, reversed so that their prongs point downward, extend through the columns, projecting equally on both sides, and are built into the upper portions of the beams and girders, thus bonding them and providing for cantilever strains at these supports. A framework of this size was considered necessary partly because of the wind pressure, the hotel being on the beach front. The building is proportioned for a wind pressure of thirty pounds per square foot of external vertical surface, and for live loads of seventy pounds per square foot on the 'exchange' and eight floors; all the other floors are proportioned for fifty pounds per square foot. The concrete is proportioned for a working load of five hundred pounds per square inch in compression, and the reinforcement bars are designed to take all tensile and shearing stress and have a maximum working load of sixteen thousand pounds per square inch.

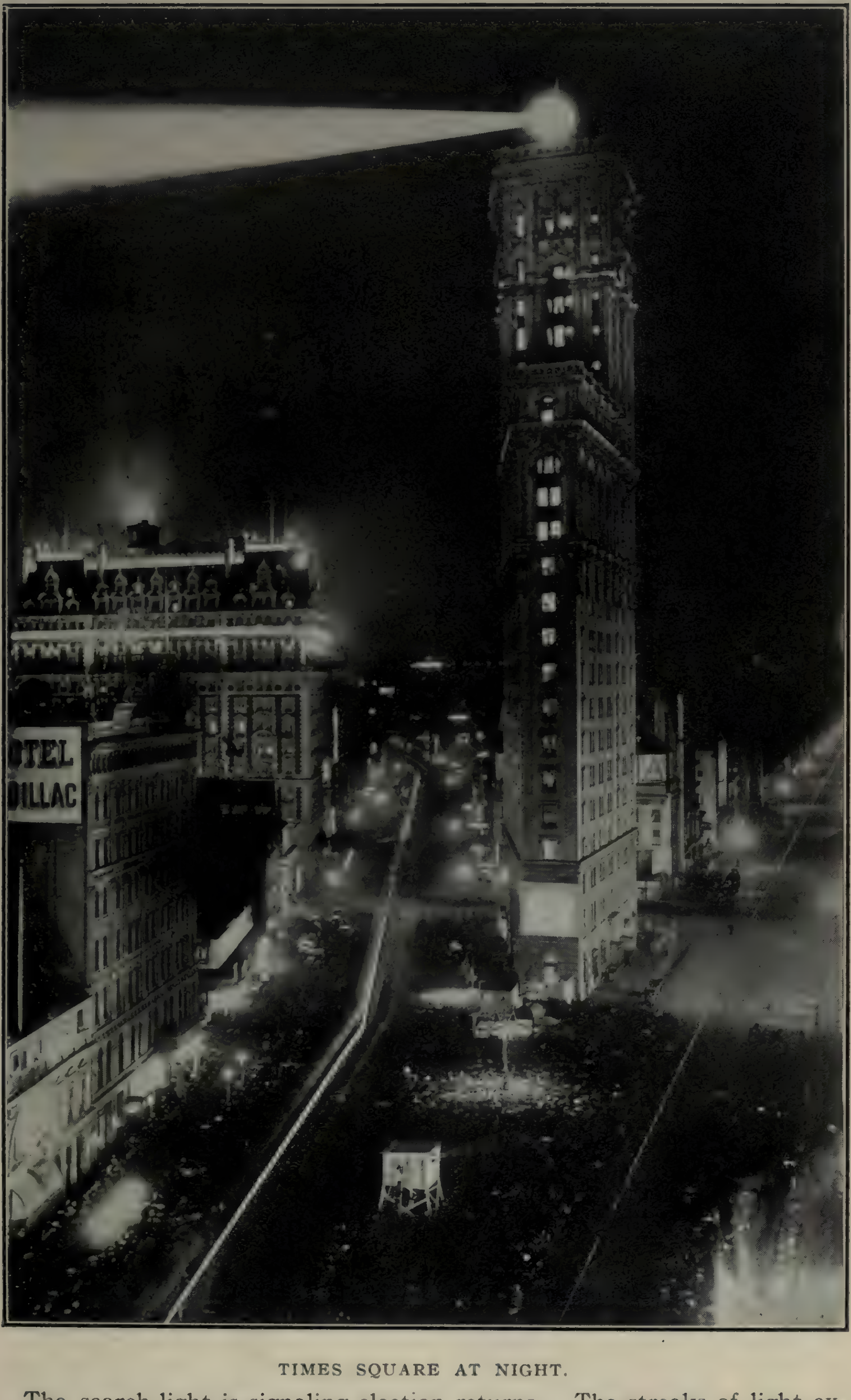
"The structure was molded, all of the framework being formed in boxes. Carpenters formed about one-half of the building force, since so many molds were required to sustain the great weight of the material. Boxes for the rectangular columns were made of planking one and a quarter inches thick, carefully fitted together, and further secured by battens and set in place by hand. In arranging the system of molds the upper ends of the columns were notched to receive the boxes for the floor beams and girders, which were fitted into them, supported on the ends of the vertical boards and on transverse cleats nailed to both members. The ends of the girder boxes were thus set flush with the inner surfaces of the column boxes and, the joints being thoroughly nailed, were considered by the contractors tighter and more satisfactory than if made in any other manner. The girder boxes were simple rectangular troughs, made like the column boxes, and were supported at intervals between columns on vertical shores with their ends double knee-braced to transverse cleats on the bottom of the boxes.

"The reinforcement bars for the columns were wired together in the iron-yard to make rigid frames with the bars in accurate relative positions, and were deposited as units in the column boxes and were carefully wired into position. Concrete was wheeled on runways laid on the girder boxes and was dumped from the wheelbarrows into the boxes. Special care was taken to compact it and work it well around the reinforcement bars and eliminate all chance of empty space by constant tamping. In the column boxes long-handled spades or simply straight poles were used to work between the reinforcement bars.

"In the girder boxes a thin layer of concrete was first spread on the bottom, and then the reinforcement bars were placed accurately on it and moved back and forth until thoroughly set in position, when the remainder of the concrete was filled in and carefully spaded around them. The concrete was leveled off with a straight-edge two inches above the tops of the tiles, making the floor slabs, the beams, girders, and columns monolithic and providing a continuous horizontal surface over the full area of the building, from out to out of the walls, about two inches below the top of the finished floor. After the concrete had set at least ten days, the boxes were stripped from the columns and girders, the timber was roughly cleaned and made up again for use in an upper story. The inner faces of the boxes were scraped clean, but not oiled or coated.

"By this method but a small number of mechanical appliances were required. The concrete was composed of Portland cement and trap-rock of three-quarter-inch size. It was mixed in portable concrete-mixers and that used in the foundation and lower stories delivered to wheelbarrows to be trundled to the work. That for the remainder of the building was delivered from the mixer through a movable chute to a hoisting-bucket. This chute was seated on an inclined bed to which it was connected by a lever that could be operated to set the lower end of the chute over the concrete-bucket or to slide it back and up so that the lower end cleared the bucket, and the latter could be hoisted or lowered past it. The concrete-mixer and tower were placed in the most central position available so as to minimize the wheeling-distance. Adjacent to it there was a hod elevator on which tiles and other material were carried. The hoist delivered the concrete to an elevated platform or chute, closed with a gate at the lower end, which was raised to discharge the concrete into the wheelbarrows below."

The average rate of building on this hotel was one story to every six days, but there were both day and night shifts of men, so that the full twenty-four hours of each day were utilized. Despite this the operations were so relatively noiseless that there was little cause for complaint by people living in the vicinity. The suppression of sounds is an incidental but pleasing feature of this kind of construction.



TIMES SQUARE AT NIGHT.

The search-light is signaling election returns. The streaks of light extending down Broadway and Seventh Avenue, respectively, represent the moving headlights of trolley cars, and show that the photograph is a time exposure.

IX

FURNITURE AND FURNISHINGS

BY many writers on the subject it is held that all house furniture of Western Europe and America has a common ancestor in the feudal chest of the Middle Ages. For after the fall of the Western Empire in the fifth century, Europe seems to have forgotten the use of most articles of furniture except the chest, even such simple things as chairs not coming into general use until something like a century before Columbus' great discovery.

For many hundreds of years the chest seems to have been the one characteristic piece of furniture of the movable type. It should not be inferred, however, that all chests were the simple trunk-like structures known by that name to-day, but rather that most of the simple pieces of furniture of that time partook of many characteristics of the chest. Chairs were not made with four legs as at present, but were small chests with high backs attached; settles were simply elongated chests with high backs and side-pieces; movable beds, when used at all, were long, wide chests. Most beds at that time were built into the wall and were not movable pieces. Such articles of furniture as wardrobes, sideboards, bureaus, etc., were unknown, and when finally developed were made first as modified chests.

When the feudal lord and members of his household moved from place to place most of their possessions were taken with them. In the chests belonging to the household were placed all the plate, jewels, ornaments, and tapestries from the halls, to be carried away to the next resting-place. On arrival these chests were unpacked, the tapestry hung upon the walls, and certain articles removed and placed about the rooms, the chests themselves being used as a storage place for clothing and valuables, and serving also in the capacity of couches and chairs.

Even such simple conveniences as wardrobes for hanging clothing were not generally used, clothing of all kinds being kept in the chests. But the inconvenience of digging out articles of clothing and valuables from the bottom of these great chests led finally to modifications, first in the smaller ones, and later in the larger, until finally drawers and "chests of drawers" were developed. The wardrobe, or clothes-press, was also a simple evolution of the chest made by standing it on end so that the clothing could be hung from pegs and not folded in the boxes except during the times of moving.

The modern box-couch is perhaps the nearest direct lineal descendant of the old feudal chest. In fact, aside from the springs, it is practically identical in structure with its ancient prototype.

Some of the first medieval chairs were made as small chests with backs and arm-pieces as temporary additions, which could be removed when necessary. When these became fixed parts they were often built very high at the back and with deep sides, not for ornamental purposes as at present but as protection against cold draughts. This was essential to comfort in medieval dwellings, whether castles or cottages, as their crude structure and ill-fitting doors and window-casings did not keep out gusts of wind. Even the draperies hung about the walls were, in many cases, used for protection against the wandering gusts rather than for ornament.

The tables of this period were relatively light structures as compared to the heavy, high-backed settles and chairs. People did not draw their chairs up to the table, as at present, but had the table drawn up to the chairs, or long settles along the sides of the halls. In this manner only one side of the table was used by the diners leaving the other free for the serving-men. For convenience in handling, these tables were made of light material, and it was not until movable stools, benches, and finally chairs came into use, that the great dining-tables calculated to accommodate guests on all sides began to be constructed.

But even the chairs used with these tables were ponderous structures with arms, and this type of heavy armchair remained in general use until hoop-skirts came into fashion. Women wearing this inconvenient form of apparel found it impossible to manage their skirts when they attempted to sit in these chairs. For their convenience, therefore, the arms were shortened and cut away at the sides, and eventually the entire structure lightened until the modern chair was evolved.

This evolution did not take place, however, until the beginning of modern times. And yet, had the customs of the ancients been studied, models of chairs, practically identical with modern ones, would have been found to have been used by certain nations at least two thousand years earlier. The Egyptians, for example, were accustomed to use light, portable chairs, very like our simple modern ones, and the Oriental nations seem to have continued using such chairs throughout the ages. Among these nations the chairs were carved and richly ornamented in practically the same manner as in modern times.

The period of the Renaissance marks the beginning of the time of modern furniture, graceful styles and rich ornamentation being gradually introduced until the culminating period in the time of Louis XIV and XV in the seventeenth and eighteenth centuries. The elegance of furniture in these periods, the graceful styles, and costly carvings are too well known to need description here. These styles are still copied, coming into fashion periodically, although the custom of such monarchs of fashioning some of their furniture in silver has never been popular even with the wealthy since their time. This silver furniture in the palaces of the last of the French Bourbons was eventually melted to defray expenses by the descendants of those monarchs.

In recent years America has taken an important place in the construction of convenient and comfortable articles of furniture. Even in Colonial times the rocking-chair had become popular, but this particular article of furniture was purely an American invention, and has never come into general use in Europe. Chiffoniers, folding-beds, and refrigerators are also American inventions, and the comfortable "hammock chairs" are simply adaptations of the primitive hammocks used by the South American aborigines and apparently unknown to civilization until the advent of the Spaniards.

The use of machinery has revolutionized furniture-making quite as completely as it has any other single field of industry. The past half-century has seen cheap, substantial, and really very ornamental furniture placed within the reach even of the poorer classes, this being due entirely to the use of machinery. The most expensive furniture is still made in practically the same manner as it was two centuries ago, but furniture quite as useful, and frequently indistinguishable from it by the ordinary observer, is now turned out entirely by machinery, no handwork of any importance being employed at any stage of the process. Some of this machinery, such as saws, planing-machines, and boring-machines, are too familiar to need further description; certain less familiar mechanisms will be referred to more at length presently.

THE PASSING OF HAND-CARVING

For many centuries, even during the time of the Dark Ages, the carving of wood held a position as a fine art in Western Europe. For certain purposes such carving took the place of sculpture in stone and was considered ideal for the richer furnishings of churches and palaces. With the improvement of furniture-making at the time of the Renaissance, this fine wood-carving increased in popularity, flat-relief work coming into favor as well as the more elaborate carvings which later characterized the artistic furniture period of France in the seventeenth century.

With the invention of the steam-engine, however, and the introduction of machinery into all fields formerly confined to hand-labor, efforts were made to find some substitute at least for the rougher hand-carving. With the powerful machines that came into use, the softer woods could be pressed or punched out into rough, decorative patterns, produced so inexpensively that even the cheaper classes of furniture could be made with decorations imitating in a rough manner the art of the wood-carver.

Such rough pressed work, however, was such a shoddy imitation that it did not compete to any extent with the better-class work of the hand-carver. The products of the hand-tool were still in demand as much as ever in fine furniture, despite the fact that ornate, machine-made, cheap furniture was flooding the market.

But meanwhile the mechanic was turning his attention to perfecting mechanical devices for working in wood, and very shortly a machine was invented with which patterns could be gouged out mechanically in rough imitation of the wood-carvers' hand-work. Those machines were of various patterns, but a very common type was that of a whirling chisel which could be guided up and down, or in any direction laterally, cutting out the wood wherever it touched. It was, in fact, a reversal of the principle of the turning-lathe, the tool itself doing the revolving instead of the wood.

The whirling tool was fastened to a movable arm above a piece of wood on which a pattern had been drawn or stamped. By setting this machine in motion, the workman, by guiding the whirling chisel over the surface marked by the pattern, could carve out the wood much more rapidly than could be done by the hand-carver. Such mechanical carving was rough and unfinished as it came from the machine, but a few hours of additional work by the hand-carver could quickly convert it into a well-finished product, scarcely distinguishable from the coarser forms of hand-carving.

Such machines at once menaced the profession of the wood-carver. Their work was so rapid, their manipulation so simple, and the results so closely resembled hand-carving that there was little choice between the two in certain grades of work. The difference in the cost of production was, of course, enormous, and what still further menaced the wood-carvers was the fact that an unskilled workman might operate such a machine. Almost any workman could learn to follow a pattern with a little practice, so that the services of trained wood-carvers would only be necessary for giving certain finishing touches, or for doing the very finest work in factories. Thus many wood-carvers found themselves confronted with the necessity of remaining idle or accepting positions as machine operators at the pay of unskilled workmen.

But the end of the degradation of the wood-carver was not yet. Improvements were being made constantly both in the carving-machines themselves and in the methods of using them, until these machines were able to produce work of such perfection that even the finishing touches of the hand-carver were unnecessary. And presently, these machines were so improved and made in such a manner that instead of turning out a single piece of carving at one time half a dozen or more duplicate carved pieces could be made by the workman at one time.

The principle on which these machines work is that of the familiar drawing implement, the pantograph. In this instrument, two arms are arranged so that the drawing-points upon them move always in parallel directions and at equal distances. By this arrangement it is possible to draw two exactly duplicate pictures at the same time, or to copy a picture already made by passing one of the points over the outline of such a picture, while the other marks on a separate sheet. In this simple copying pantograph no provision is made for the points moving in a vertical direction, only a lateral movement being necessary. But by adopting the same principle and having two points always at exactly the same relative distance from each other, vertical as well as horizontal duplicate movements in any direction may be made.

This was the principle now adopted in these duplicating carving machines, where six, eight, or even a dozen whirling chisels, arranged one above the other in a vertical frame, all act in unison, following exactly the movements of the pilot implement guided by the workman. With such a machine the workman consumed no more time or effort than in manipulating the more simple device, but when he had finished tracing the pattern before him he had carved not merely a single piece of wood, but perhaps eleven other duplicate pieces equally well. Obviously such machines greatly reduced the cost of mechanical carving, since one operator performed the work of twelve.

Another modification soon made it possible for very unskilled workmen to do duplicate carving. In place of making the guiding, or pilot tool, in the pantographic series, actually perform work of cutting, this was used as a dummy in the machines, merely following the surface of a piece of carving and guiding the duplicate tools. In this manner a carved model was used in place of a board with the pattern outlined upon it, the dummy chisel passing over every part of the surface, causing the other chisels in the series to follow the course of the pilot chisel, but cutting instead of merely passing over it.

As the result of this arrangement a skilled workman was no longer required to do the carving. Given a carved model, a boy could guide the dummy chisel over its surface and make duplicate carvings as well as a highly paid man. The carved model could be used an indefinite number of times, and duplicate carvings could be turned out for a very trifling sum.

Nor was the quality of some of this machine-made carving to be despised, even from the standpoint of the hand-carver. By using carefully adjusted sets of chisels of various sizes, almost all kinds of delicate carving could be done in duplicate by skilled workmen —carving that could not be distinguished from handwork except by the expert. And when a few finishing touches of hand-work were given, the deception was complete. The result was that the market was soon flooded with well-carved furniture at a price within the reach of many besides the opulent.

All this, of course, was disastrous to the art of woodcarving. The older carvers could not compete by hand with such machinery, and apprentices hesitated to adopt a calling that promised so little for the future. The position of the wood-carver was thus made analogous to the position of the wood-engraver, the mechanical carving-machine throwing the one out of employment, just as the process of photographic reproduction of pictures had done in the case of the other.

It should not be understood, however, that fine hand-carving has entirely disappeared any more than has fine wood-engraving. There is still a restricted market for both, and will be in all probability for all time to come. The aggregate amount of hand-tool work, however, is only a small fractional part of the total amount of carved wood produced every year. But even this kind of hand-carving is not followed along exactly the same lines as formerly. The hand-carver, even of high-class carving, now hastens his work with certain mechanical cutting implements, modifications of the kind used on the pantographic machines just referred to, or by some of the marvellous lathes now made. By this compromise the cost of fine wood-carving is greatly reduced, and a limited number of fine wood-engravers given employment.

OTHER INGENIOUS TOOLS USED IN FURNITURE-MAKING

The mechanical carving-tools just referred to give some idea of the ingenious machines now used to perform work formerly done by tedious hand-methods. Among these the belt-saw should be mentioned. This saw, as its name indicates, is made in the form of a continuous steel band having one edge fitted with teeth, and running over wheels like the leather belt of ordinary machinery. This saw has the advantage over the ordinary circular, or jig-saw, in the fact that it can be tilted so as to saw at an angle, thus cutting bevelled edges.

The time-honored turning-lathe, just referred to, has also been improved, so that in place of turning only relatively simple patterns, circular in form, those of almost any size or shape may be made. Some of the most beautiful and complicated pieces of woodwork closely resembling wood-carving are now made on this machine. One of the most useful forms of the lathe, however, is the very simple one with which veneering is done.

The art of veneering is almost as old as cabinet-making itself, and the process of applying the veneer is practically the same to-day as it was several centuries ago. This consists in gluing a thin layer of wood upon some underlying timber, usually of inferior quality, for improving the latter's appearance. In this manner imitations of valuable furniture may be made at comparatively small cost. It should not be understood, however, that all veneering is done for purposes of deception, or that the wood over which a veneer is placed is always of inferior quality. Some of the best solid mahogany furniture is made with veneered surfaces, this being done because it is frequently possible to obtain more beautiful effects of the grain by using the veneer than by simply polishing the surface of the solid wood with the grain exposed as it appears in the tree itself. In such cases a thin veneer of beautifully grained mahogany is glued to the underlying mahogany wood, this veneering being sometimes scarcely thicker than a sheet of paper.

Two methods are used in preparing wood for veneering, one by sawing the timber into thin plates, the other by slicing it with knives. By the sawing method it is possible to obtain a somewhat better grade of veneer on account of the position of the grain. The older method of sawing was done by hand, the successive layers being removed one at a time, but the modern method is to cut several layers at once by means of thin saws placed in parallel close together. In both of these methods there is a waste of wood corresponding to the thickness of the saw which is sometimes thicker than the veneer itself; and as this process is relatively slow it is not used except for making the highest grade of veneer.

A more economical and rapid process is the method of slicing by turning off continuous layers from logs in mammoth lathes. In cutting by this method the logs are sawed into proper lengths to fit the turning-lathes, some of these machines being able to turn logs ten feet or more in length. The logs are then placed in great tanks of hot water which are heated by steam coils, and are then steeped and soaked until the outer layers of the wood are thoroughly softened. As most of the wood used in veneering is of an extremely dense structure, this soaking process requires some time, frequently many weeks, before the logs are softened to a sufficient depth for cutting.

When ready for cutting these logs are taken from the soaking-tanks and placed at once in the great lathes. Here they are revolved in such a manner that a thin layer is sliced off along the entire length of the log, the cutting-knife being so arranged that the entire outer surface of the log to a depth of several inches may be removed as a continuous sheet resembling paper as it comes from the roll of the modern printing-press. These great sheets are absolutely uniform in thickness, and as they emerge from the lathe are cut off in widths of convenient size, dried, and piled up like reams of paper.

In this manner a log two feet in diameter may be pared continuously until it has been reduced to a thickness of nine or ten inches. The amount of veneer furnished by such a log is determined of course by the thickness of the shaving, but at the usual thickness, it would furnish something like thirty thousand square feet of the material.

As just noted, veneering cut in this manner is not usually considered of the finest quality. The direction of the grain is not the most advantageous for producing beautiful effects, and the steaming process injures the coloring to some extent. Nevertheless, this process is so rapid, cheap, and without waste, that it is popular for making all but the very finest grades of veneer.

X

THE PRODUCTS OF CLAY AND FIRE

AT just what period in his evolution primitive man may have learned to mold crude vessels out of clay and harden them in the sun, or how he came to learn this at all, must ever remain a matter of conjecture. It is certain, however, that the first steps of the process were taken ages and ages before the dawn of history, perhaps even before our primitive ancestor had learned to use fire in preparing his food. The idea may have been suggested to him by noticing that his own footprints in wet clay became hard, stonelike receptacles when the clay had dried in the sun. Once he had noticed this, the idea that useful vessels could be molded out of this same plastic substance and dried in the sun would sooner or later suggest itself to his mind.

But such crude clay vessels would be of little use for holding liquids, since sun-dried clay absorbs water readily and becomes soft. They could be used for holding dry substances, however, just as similar vessels are used for this very purpose to-day in rainless Egypt. Still they would be of relatively little value as compared with vessels made in the same way, and hardened by fire. When men had learned to harden the clay by burning it, they had at hand material from which they could make all manner of useful things that would be as enduring as rock itself. So enduring, indeed, that these crude products of the first potters, together with their fossil remains, form the most important records of prehistoric man.

Obviously, primitive man must have learned the use of fire before he learned to make fire-baked pottery; and it is more than probable that it was some accident with the "untamed element" that taught him how its very fury could be thus turned to account. A conflagration that destroyed his home may have converted the clay-daubed walls of his hut, which could hardly hope to endure the first prolonged rainstorm, into a stony substance all but indestructible. Or in raking the ashes of his burned home in the hope of finding some cherished article that had escaped destruction by the conflagration, he may have found that his crude clay dishes, far from being destroyed by the fire, had been transformed into a new and infinitely more useful material, while still retaining their original shapes. Some such hint would be sure to come sooner or later to every race of people living in a tropical or temperate zone; and it would follow inevitably that this hint would be taken advantage of, and the art of pottery-making discovered.

In point of fact, practically all the primitive races are familiar with some kind of pottery-making. The peculiarly low-type savages of Australia have never learned it, nor have the natives of Greenland and other arctic regions; but the reason for this ignorance on the part of the arctic dwellers is explained by climatic conditions. In a land that is buried under snow most of the year and where the only fuel obtainable is the fat of animals, there is no chance for the discovery of an art requiring an abundance of earth and fuel. But similar races living further south had learned the art, and were very skillful potters, centuries before the dawn of civilization. The remains of pottery left by the prehistoric mound-builders and cliff-dwellers in America, for example, show that they had acquired quite a high degree of skill and knowledge of the art.

All Western races were centuries behind the Eastern Asiatics in learning the art of making high-grade pottery. The Chinese and Japanese were making glazed pottery at least two thousand years before the secret of its manufacture was learned by Europeans, who had to content themselves with unglazed ware until the eleventh century. Then the Western potters learned to coat their rough vessels with a silicious substance, which, when heated to the melting point, formed a glassy coating over the surfaces of the ware, not only enhancing its beauty, but rendering it non-porous. For it should be remembered that unglazed pottery is very porous and absorbent. It cannot be used for cooking and will not retain liquids for any very great length of time unless coated with some waxy substance. It played no such important part in civilization, therefore, as the metals, after methods of working these substances were discovered, until the art of glazing became known. Then earthenware took its place beside iron itself in usefulness. Iron, brass, and pewter cups and dishes were gradually displaced by earthenware vessels in the kitchen; earthenware jugs and jars took the place of wooden tubs and kegs in the cellar; while retorts and beakers that resisted excessive heat and the action of the strongest acids in a manner quite unknown before, came into use in the laboratories of the alchemists, and played an important part in establishing the science of chemistry.

It should not be understood that the knowledge of forming a glaze on certain kinds of pottery was confined to the Chinese for so many centuries before Western Europeans attained it. The Egyptians knew something of the matter; and the Greeks used a thin glaze on their ware. The Romans adopted a glazing process from the Greeks, and seem to have invented a glazed ware of their own, which they scattered far and wide over their domains. But this art of making glazed pottery seems to have been forgotten by the Western nations during the Dark Ages, if, indeed, they had ever learned it; and it was not until five or six centuries after the fall of the Roman Empire that the art was revived, or rediscovered. It is significant that this revival came at about the time that the straggling Crusaders were making their way back into Europe, bringing with them so many useful ideas gathered from the despised infidel in the Holy Land. It seems more than likely, therefore, that the Arabs may be indirectly responsible for the introduction of glazed pottery into the West. If so, it is simply one more link in the chain of evidence to prove that the Crusades were among the most useful and successful series of warlike expeditions ever undertaken, although they failed so completely in attaining the object for which they were projected.

THE MANUFACTURE OF POTTERY

The processes necessary to the manufacture of pottery are many, and range from the simplest to the most complicated and delicate. Yet in a general way the methods have been the same all over the world throughout the ages, until the nineteenth century, when the introduction of machinery in the Western nations changed their methods and gave them the advantage over the Orientals in the better forms of commercial pottery. The potter's wheel—a revolving horizontal disk upon which the clay is molded—had been the most essential machine to the potter in Asia as well as in Europe, as it had been two thousand years earlier in Greece and Rome, and still earlier in Egypt. Nor should it be understood that power-driven machinery replaced it, or changed it materially except in the matter of adaptation of its driving mechanism. For certain kinds of wares, where the individual skill of a workman is essential, the potter's wheel is likely to remain always in use; but in the great factories, even where very fine grades of commercial china are made, the wheel is now gradually being replaced by other machinery.

But the potter's wheel, while so essential to the manufacture of fine earthenware, was not responsible for the improvement in the ware from the unglazed, crudely fashioned vessels of the ancients to the modern finished product; nor was the improvement in any machinery responsible for it. The wares of Charpentier, Josiah Wedgwood, the Davenports, and Hirschovel, were superior to those of the earlier periods, not because these masters had greatly superior implements, but because they understood methods of blending and applying their materials better than their predecessors. Knowledge of the methods of making fine chinaware preceded the introduction of perfected mechanical devices for manufacturing it.

In making most fine pottery, two separate heating processes are necessary. The first of these, which precedes the glazing, is known as the "biscuit fire," and the unglazed ware as it comes from this oven is known technically as "biscuit." This firing shrinks the ware, and converts the clay into a firm, brittle, stony substance, very porous and absorbent. This cannot be reconverted into plastic clay by any known process, although its chemical constituents are practically the same. The second firing is done after the glazing material has been applied to the biscuit by one of the various methods that will be described a little later, the heat of the glost-oven, or glaze-kiln, melting the glazing material, which becomes an integral part of the ware itself.

THE RAW MATERIALS

Generally speaking, the materials for making fine pottery may be divided into four classes. In the first are the plastic clays—China-clay (kaolin), "ball" or "blue" clay. In the second are the glass-forming materials used in the body or in the glaze. In the third, flint and quartz, sometimes called "indifferent substances." And in the fourth, the coloring agents, made of metals or metallic oxides. Most of these substances are natural products. Their chemical composition is well known, and many of them can be produced synthetically in the laboratory; but good pottery can not be made from these artificial products. The composition of clay, for example, is no secret, but laboratory-made clay has not the peculiar plastic quality of natural clay so essential to the potter.

Chemically, clay is a hydrated silicate of alumina in combination with slight quantities of such substances as iron, lime, soda, or potash, and is the result of the decomposition of felspathic rocks. It is much richer in alumina than the rocks, however, since alumina, being so light a substance, is held longer in suspension while the heavier materials settle to the bottom. From the potter's point of view the most injurious substance contained in clay is iron, owing to its coloring properties. If every trace of this metal is not removed, the pottery as it comes from the ovens will be "off color." The slightest trace, too small to be noticed readily by ordinary tests, will give the disfiguring stain when the ware is placed in the firing-kiln. Larger quantities give the familiar red color seen in bricks and flower-pots, although no such color is apparent in the clay before firing.

It should not be understood that every kind of clay is suitable for pottery-making. The clays from which such coarse substances as bricks and flower-pots are made, for example, contain too many other impurities besides iron to make them available for pottery. Brick clays are common in almost every country and climate. Not so the "blue" or "ball" clays. The available beds of these are comparatively few, some of them lying from sixty to a hundred feet below the surface of the ground. But even when covered to this depth, the substance is of sufficient value to pay for its excavation and removal. As it comes from the beds it is of a bluish color, due to organic matter; but when this is removed by moderate heat, the clay becomes practically pure white. As found in nature the stratum of clay is from three to six feet thick, usually covered by a layer of sand. For shipment, the clay is cut into blocks of a size convenient for handling, which, when dried, have the appearance of gray stone.

The chemical composition of blue or ball clay, according to Muspratt, is as follows, although different specimens would show variations from this:—

Silica	46.38	Lime	1.20
Alumina	38.04	Magnesia (trace)	
Protoxide of Iron	1.04	Water	13.44

The mass of any clay varies with the amount of water it contains. When dried, some clays lose as much as thirty per cent. in weight. On the other hand, if clay is stirred in great quantities of water, its particles are so small and so light that a homogeneous mixture having the consistency of thin syrup can be made. From such mixtures the impurities are removed more readily than would be possible from the clay in the natural state. The exact amount of solid substance per pound can also be determined more readily and more accurately than in the more solid forms. For these reasons many pottery establishments mix all their ingredients in water, the mixtures being known technically as "slips." The exact amount of solid material contained in each slip is known, and may be easily measured in the simplest manner. For example, a pint of ball-clay slip that weighs twenty-four ounces will contain approximately six and one-half ounces of dry material. If this is the proportion desired the workmen can easily obtain the necessary mixture by adding water to the clay which is stirred, or "blunged," so as to be of uniform density, until his pint measure when full tips the scales at the twenty-four ounce mark.

Of course it is possible to reduce all the materials to a perfectly dry state, mix them in the desired proportions, and bring them to a workable plastic state by the addition of water; and this method is used in some of the large factories. The usual method, however, is to make slips of the different materials, each slip of predetermined strength, mix them all together, and then remove the excess of water.

China-clay, the other substance coming in the first class of materials, is a white, earthy substance, easily pulverized. In this country it is very generally called kaolin. Like the blue clay it is found in many different countries, China and Japan, Germany, France, England, and several other European countries, as well as in certain places in America. As it contains many impurities wherever found, it must be washed before being used for making pottery. This is done by adding large quantities of water until a thin "solution" is made, when the impurities, which are heavier than the kaolin, settle to the bottom. The lighter particles of the clay may then be run off.

It is a peculiar characteristic of this clay that the commoner qualities are the more plastic and require less care in handling than the finer grades. None of them are as plastic as the ball clay, however, but they contain very little of the objectionable iron. This clay is used in the pottery to strengthen it against heavy weights and sudden changes of temperature, as well as to increase its whiteness. Muspratt's analysis shows it to contain substances in the following proportions:

Silica	45.52
Alumina, with a trace of oxide of iron	40.76
Lime	2.17
Potassia, with trace of soda	1.90
Magnesia, phosphorus (traces), and sulphuric acid (traces)	
Water, with small quantity of organic matter	9.65

For the glass-forming materials used in the body of the earthenware, as well as in the glaze, a granite in which the felspar is incompletely decomposed and which is still fusible because of the presence of alkaline silicates, is used. It is called china-stone, or Cornish stone, since the English supply comes from the hills of Cornwall. It is rich in silica (about 73 per cent.) but contains also about 18 per cent. of alumina with small quantities of lime, magnesia, traces of iron, and from four to six per cent. alkali. It is prepared for use by grinding between millstones.

Flint, which is classed as an "indifferent substance," is an oxide of silicon (SiO_2) which contains certain organic substances, and sometimes iron, in its natural state. It is used in the ware to prevent contraction and give whiteness. It is widely distributed in the earth's crust, but the best flint for the potter's use is obtained near Dieppe, in France. It is prepared by calcining in furnaces, then crushed in a stone-crusher or stamp-mill, and finally ground between millstones. As in the case of all substances that are ground for use in the potteries, this grinding process is a delicate one, from the fact that impurities may be introduced. Thus, if the millstones contain an excess of lime, or iron, or coloring matter, the ground product may acquire these substances, and thus be rendered unfit for use in making fine pottery. And this might not be discovered until the ware had been molded and fired, involving great loss of time and material.

The determination of the proper degree of fineness in grinding is made by passing the substance through silk or wire lawn, although an expert can tell the condition with wonderful accuracy by testing it between his teeth or nails. When no grit can be detected the substance is fine enough for the potter's use.

No matter how pure the natural clays may be, there is always present a trace of the oxide of iron, which would give the ware a yellowish tinge after firing if not counteracted by the use of a "stain," as it is technically called. The stain is an oxide of cobalt—a beautiful deep blue which is not affected by heat. A sufficient quantity of this is mixed in the "body" to neutralize exactly the yellow stain of the iron, so that the ware will be pure white, just as bluing is used in laundries for whitening linen.

The principal source of cobalt to-day is Hungary, although it is found in many other countries, and has been used for centuries by Egyptian, Chinese, Arabian, and other potters. The purest form of cobalt is obtained as a by-product of nickel. It must be ground to impalpable fineness before using in pottery, or otherwise small blue specks will appear, as may be seen frequently in the cheaper forms of earthenware.

It is apparent, even from this brief description of the processes preliminary to the manufacture of pottery, that there is a wide gap between the work of the primitive potter who molded a handful of clay and placed it in his fire, and the modern scientific methods that have developed from this simple process. Yet in all the succeeding steps in the manufacture of the ware there are quite as wide gaps, which have been bridged by modern chemistry and mechanics.

MIXING THE MATERIALS

The first step to be taken in the manufacture of pottery is that of mixing the prepared products in the proportions required. Two of these mixtures are necessary, one for the "body," the thick substance of the ware itself; the other for the "glaze" or thin coating of vitreous substance covering it.

The essential qualities of the body mixture, as stated by Sandeman, are as follows:

"It must be sufficiently plastic to be easily workable. It must be sufficiently infusible to prevent collapse in the ovens, but sufficiently fusible to become dense and sonorous. It must have sufficient stability to resist excessive contraction and must not become crooked. It must be sufficiently free from coloring matters to become clean and white after firing."

The exact proportions in which the various prepared materials are mixed, and the method of mixing them, vary, of course, with the results desired, as well as with the individual preferences of the manufacturer. Every manufacturer has formulas which he considers either better, or more expedient for his purpose. Roughly speaking, however, some formula like the following is used in most factories, the quality of materials making a little difference in their relative proportions:—

Blue clay	10–15	parts.
Kaolin	8–9	"
Flint	4–5	"
Stone	2–3	"
Stain (sufficient to neutralize yellow color)		

Each of these substances must first be brought into a state of suspension in water, so that the mixture represents a definite weight to the ounce, and is uniform throughout, after which all the substances are mixed together thoroughly, and sufficient water drained, or pressed out, to leave a plastic mass of the proper consistency for molding and working. The mixing process is called "blunging." Formerly it was done by hand, the substance to be blunged being thrown into wooden tanks, the right proportion of water added, and the mixing done with wooden paddles, hoes, or rakes. In up-to-date potteries, however, mechanical blungers are now used. These are octagonal tanks, in which several propeller-like blades are arranged to revolve horizontally, on the principle of the Archimedean screw, so that the liquid in the tank is kept constantly circulating in all directions, drawn upward and laterally by the action of the blades, and descending by the action of gravity. The octagonal sides of the blunger help in the mixing process, the particles being jostled against the angles, whereas in a circular tank they might be carried round and round.

In large factories there is at least one blunger for every one of the several materials to be used in making the body. When these materials have all been brought to the proper density and churned until the mixture is uniform throughout, they are passed on to the mixing "arks." The mixing arks are made on the same general principles as the blungers, although they differ somewhat in the details of construction. For convenience they are frequently placed on a lower level than the blungers, and into them the blunged material is pumped, or run, passing through one or more sieves which arrest all lumps, or particles of foreign material.

There are many ways of measuring the exact proportions of the blunged materials that are to go into the mixing ark, such as weighing, or measuring in pails or dippers of a certain size. But as all these methods take much time, and sometimes prove inaccurate from the possibility of mistakes in counting, the potter usually prefers to make his measurements with what he calls a "mixing staff." This is simply a lath with nails driven into it at intervals, each nail representing the height to which each slip of the mixture must reach when the staff is thrust upright into the ark. It makes no difference to the measurer using such a staff, therefore, whether the liquids from the blungers are pumped, dipped, or run into the ark, as his guide is the rise of the liquid of the mixture along his staff until the indicating nail is reached.

Of course, since different quantities of each slip are used, the nails in the staff will be placed at unequal intervals, and it is necessary that the slips be run into the ark in a definite order. Usually the lighter materials, blue clay and china clay, are introduced first, to facilitate mixing, followed by flint, stone, and, lastly, the stain. As soon as this last is introduced, the machinery is started and the churning process continued until all the particles of the different substances are held uniformly in suspension throughout the mixture.

From the mixing ark the slip goes to the "lawns," which, as their name indicates, are sieves made of either silk or wire with fine meshes of a definite size. These are arranged in "lawn boxes" in two or three tiers, one above another, the coarser lawns being at the top where the stream of slip first enters. This straining-out process removes the coarser particles and bits of foreign matter, but there may still remain very minute particles of iron, small enough to pass through the meshes of the lawns, yet large enough to make stains in the finished ware. To remove these magnets are placed in the stream of slip as it comes from the lawn box, and magnets are often placed in the "finish ark," the churning device into which the slip is run from the lawns, and in any other place where a chance particle of the metal might be found. For, as we know, iron is the arch enemy of the potter. It is in the original clay, and as the machinery of the factory must necessarily be constructed of it, it menaces every operation of the manufacturing process.

The finish ark repeats the stirring process of the mixing ark, and from this the slip is passed on to the filter-presses. In these the water of the slip is squeezed out through strong cotton cloths, until the mass remaining is of the proper consistency for molding into the ware.

One more operation is necessary, however, before the material is actually turned over to the workmen. This is called "wedging," and is now performed by a machine called a "pug-mill." The object of the operation is to make all the clay coming from the presses of exactly the same consistency. In the old method of wedging by hand the workman cut off pieces of the clay with a wire and threw them repeatedly upon a prepared block until the mass was kneaded thoroughly. This slow hand-process is still used on a small scale in some of the operations of turning or pressing, when the operator's clay may have dried a little on the outer surfaces; but in the main it is performed by the pug-mill. This machine resembles a large sausage-machine in its mechanism, having a horizontal, cylindrical body in which the blades revolve about a shaft running through the center. The clay is fed in at one end of the cylinder, where it is cut, kneaded, and pressed along the body of the machine, and finally is squeezed through an opening at the opposite end, more thoroughly "wedged" than is possible by hand. As it emerges from the pug-mill it is cut off in sizes convenient for handling, by means of a brass wire, and is then ready for the workmen.

THE GLAZE AND ITS PREPARATION

There are many intermediate steps in the manufacture of pottery between the "wedging" and the final application of the glaze, but as many processes in the preparation of the glaze closely resemble those used in preparing the clay, it will perhaps be as well to consider them here.

When the peculiar qualities of a perfect glaze are considered, it is not surprising that it took so many centuries for potters to discover and perfect it. The coating of glaze when applied to ware in the biscuit state plays the same part that a coat of paint does to a wooden building—it adds beauty and gives permanence to the structure. But the comparison ends here. When fired, the glaze becomes a part of the ware it covers, not a superficial layer, as in the case of paint applied to boards. It must be sufficiently hard to resist abrasions, not affected to any extent by acids, must fuse at a lower temperature than the ware it covers, and at the same time have the property of expanding and contracting in the same ratio, or otherwise fine cracking, or "crazing" as it is called, will result. This last is considered one of the greatest defects in earthenware, although it is sometimes produced intentionally by Chinese potters in making ornamental pieces. Crazed pieces, such as table dishes, that must be put to hard usage, become discolored and eventually fall to pieces.

When we consider that the glaze is a composite of several different substances, each with a different expanding ratio; that the mixture itself will have a still different expanding ratio, which changes with the varying quantities of the substances it contains; and that this same thing is true of the body-substance of the ware, it seems almost a hopeless task to attempt to produce the right combination of the two. Yet the potter has solved this in a most practical and economical way, as witness the quantities of good chinaware now placed upon the market at a price within the reach even of the very poor. But what an expenditure of time, thought, and material wasted in experiments, the cheap little cup on the table of the humble laborer represents!

The dry materials generally used for glazes are china-clay and flint. These are combined in varying proportions with "fluxing materials," such as carbonate of lime, carbonate of potash, carbonate of soda, carbonate or oxide of lead, china-stone, tincal, boric acid, and borax. Some of these are soluble in water, and as the glaze is applied as a liquid, it is necessary to vitrify them into insoluble substances before using. This is done in the process of "fritting," which will be referred to in a moment.

Flint and china-clay give hardness, transparency, and depth of tone to the glaze. Carbonate of lime, in the form of chalk, makes the glaze harder and improves the color. It does not promote fusibility as readily as some of the other substances, borax (biborate of soda) heading the list in this respect. Indeed, borax is an absolutely indispensable substance to the potter, and in recent years the cost of its production has been greatly lessened, thanks to the work of practical chemists. Borax not only facilitates the making of the glaze, but gives great brilliancy to the finished product.

The fritting process, by which the soluble substances of the glaze are vitrified, is done by subjecting the substances to direct flames in a kiln. This kiln is a tank made of fire-brick, so arranged that the flames coming from the fire-box are reverberated down over the materials to be fritted. This reduces it to a mass of molten glass which is then drawn off into a tank of cold water. The plunge into the cold water breaks the stream of molten glass into small particles, which are more easily pulverized by the subsequent grinding process. The deeper and colder the water into which the plunge is made, the finer will be the frit particles.

The frit is ground between specially prepared millstones, or in a more modern machine, the Alsing cylinder. The particles are moistened and ground until every trace of grit has disappeared, the finished product having about the consistency of cream. It is then lawned and passed on to the blungers.

The proportions of the materials used in making the frit, and the materials themselves, vary according to the purpose for which the frit is designed, but the following formulas (by Sandeman) give a general idea of the proportions used:

Borax	120 lbs.
China-stone	120 "
Flint	60 "
Whiting	80 "
China-clay	20 "
or	
Tincal (native borax)	144 lbs.
Stone	84 "
Flint	66 "
Whiting	48 "
China-clay	24 "
or	
Boracic acid	88 lbs.
Soda ash	39 "
China-clay	37 "
China-stone	75 "
Flint	75 "
Whiting	52 "

METHODS OF MAKING POTTERY BY HAND

The last quarter of a century has seen machinery rapidly replacing hand-work in Western potteries, although the workmen themselves still find plenty of tasks, only of somewhat different nature from those of former years. It is not possible to give machinery the brain of a workman although it can be made to surpass him in speed and dexterity under his guiding hand. And so while pottery-making machines have changed the forms of occupation, they have opened new fields to the workmen, helping mankind as a whole, if sometimes injuring the individual. Its most disastrous effect seems to have fallen upon the oldest and most picturesque figure among pottery-makers, the "thrower" or man who makes his wares on the time-honored potter's wheel.

The passing of the thrower must be a source of regret to any person who has ever seen one of these craftsmen work his marvels on a lump of clay placed upon his revolving table, with no other implements than those Nature gave him. The number of men capable of acquiring the necessary skill for doing this well has always been limited even in the days before the introduction of machinery, and a long and tedious apprenticeship is indispensable.

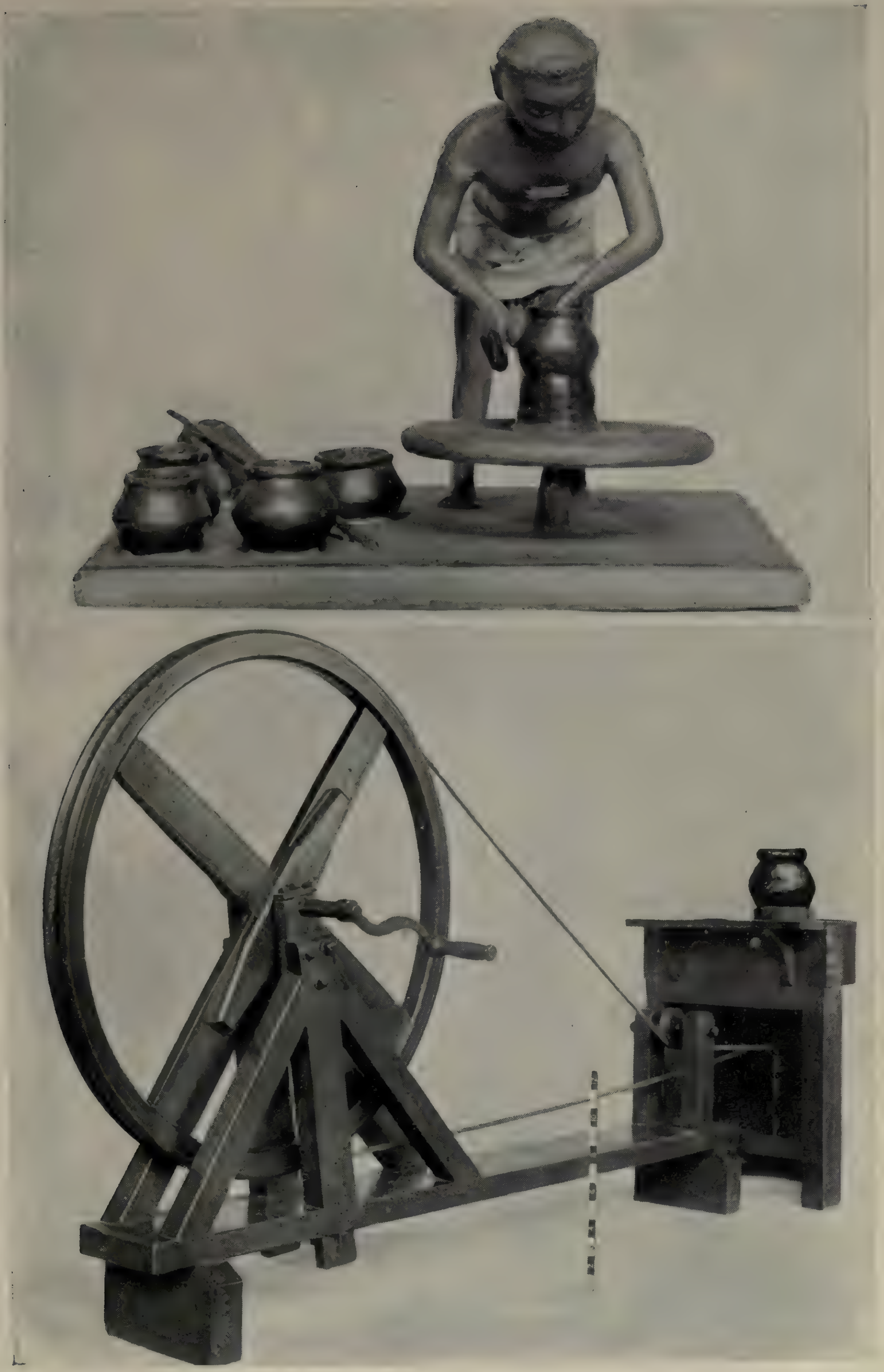
The potter's wheel is a horizontal disc of wood, so arranged that it revolves at varying speeds at the will of the thrower. In former times the wheel was run by foot power, or with the aid of an assistant who turned the disc at the speed required by the thrower. In the modern-power thrower's wheel the speed is regulated by means of cones controlled by pressure of the thrower's knee or foot.

Merely being able to fashion things at will out of clay on the wheel is only one of the requirements of the first-class thrower. In addition to this he must know the various properties of the clay he is working, including the amount of shrinkage, so that he can duplicate a finished piece of ware exactly. An experienced thrower can do this with astonishing accuracy.

Given a piece of ware to be duplicated, he first fashions a sample piece, finishing it inside and out to his liking. He then cuts the piece in half to make sure of the thickness. If this is satisfactory the weight is taken so that thereafter his assistant will hand him balls of clay of corresponding weight, which not only saves much waste of material but aids the thrower in gauging the exact size.

He begins the process of modelling the piece by dashing the ball of clay down upon the disc; then, with hands moistened, he works the revolving mass until it is free from all bubbles and is thoroughly homogeneous. He then inserts his thumbs into the center of the mass, and between his thumbs and fingers the sides of the vessel rise with marvelous rapidity into the shape he requires. If it is a large piece he may use a "rib"—an implement whose edge represents the curve of the vessel—for finishing it. But this is used simply as a time-saver, since every step of the process can be done with his thumbs and fingers, provided, of course, the opening at the top is not too small. Should this be the case the thrower makes the piece in two parts, sticking them together afterward.

In any event he must be careful to leave the clay thick enough so that the turner, whose work follows that of the thrower, will not make the finished piece too thin. In some factories, the thrower only models the piece roughly in the shape required, the final shaping and finishing being left to the turner. Obviously, crude throwing of this kind does not require the skill of the master-workman.



THE POTTER'S WHEEL.

The upper figure shows a model of the most primitive type of potter's wheel. The lower is the ordinary type of hand wheel, in using which the "thrower" requires an assistant who turns the wheel as he directs.

The more the clay is worked and molded by the thrower the better will be the ware, and any careless work on his part is likely to show in the finished piece. It may have every appearance of being well made before firing, yet as it comes from the kiln it will bear the marks of the thrower's carelessness in the form of ridges running from top to bottom, and distortion of the piece caused by variations in the pressure of the thrower's hands.

"As machines are now rapidly replacing human throwers, a few words on the decadence of throwing may not be amiss," says Sandeman. "In times gone by nearly all round, hollow ware was made by throwers, and a really skilful man not only impressed originality on any artistic work he had to do, but could also, when necessity arose, produce with astonishing rapidity a large quantity of any article exactly to size. It is not wished by this statement to insinuate that there are no such men to be found to-day, as that would create quite a false impression, but during the last quarter of a century business in pottery all over the world has increased in volume owing to a general higher standard of living and a larger demand for comforts in daily life, and the demand for throwers exceeded the supply, as the number of good throwers was always limited, and it required a long apprenticeship to learn their art, and even then very few arrived at the necessary stage of proficiency to undertake all classes of work.

"The demand, then, for the thrower was great, and there was a certain class of work which could only be made with his assistance, and this gave him an exaggerated idea of his own importance and caused him to be exorbitant in his demands, irregular in his attendance, and indifferent to the quality of his work. The largest trade being purely commercial, it became evident to manufacturers that some means had to be found to overcome this difficulty in order to produce the thousands of dozens of absolutely identical pieces that are required by trade; and it was clear that machine work was far better adapted to achieve this result than man's, as any individuality would really be a defect in pieces which were all required to be absolutely alike. The consequence has been the rapid introduction of machinery, and it was soon found that by a little thought and care in the arrangement of tools and molds, there was not a piece of ware the thrower made that could not be made off a machine, and, as a rule, made in such a way that even if it required turning, the work of the turner was much facilitated, the form of the piece approximating that of the finished article much more than the piece formed by the thrower.

"To this end the potter and machinist directed their energies with such entire success that there are few earthenware potteries, except those dedicated to artistic as opposed to commercial production, through whose doors a thrower ever passes. The result is that every day there is less demand for throwers, and fewer serve their apprenticeship, and year by year the number will grow less, and this again constantly compels the manufacturers to seek fresh methods of making any pieces still in the hands of the throwers. That thrown and turned ware has many advantages must be at once admitted. It has less contraction, has a better appearance, and is stronger than machine-made ware, and if only a few pieces are wanted, the thrower can at once make them instead of the manufacturer having to go through the costly process of modeling and mold-making; but much as the decadence of throwing is to be regretted from the artistic point of view, it must be remembered that no trade can ever be dependent on the caprices of one class of workers, and it may be taken as an axiom that when any trade finds its development checked by the action of any one class of workers that class, sooner or later, will almost totally disappear from the trade, some other method of doing their work being evolved to overcome the difficulty."

But if the passing of the thrower seems assured, the same is not true of the "turner." Turning is done on a lathe of practically the same type as that used in turning wood and metals, the workman using tools whose edges are shaped so as to make circular ribs or grooves according to the pattern of the piece. All this could be done with the ordinary tool by a skilful turner, but if a large quantity of similar pieces is to be made, much time is saved by making tools with specially shaped edges. By pressing the edge of such a tool against the surface of the revolving vessels for a moment, the turner can make an exact pattern and duplicate it indefinitely. But even with such an implement much skill is required to do good turning. The turner must know the exact amount of pressure to exert, and maintain that pressure uniformly. He must be able to determine when the clay is sufficiently dry and firm to be worked, and yet not so dry that it will come away as dust instead of in the form of shavings. He must, in a word, be a skillled workman, capable of turning out perfect work with the ordinary flat tool, but using special tools for expediency. With these tools and by means of the various adjustments of his lathe, he is able to produce not only circular forms, but also oval ones, as well as wavy lines, and rows of figures, in a matter of seconds, which would require much more time to produce in any other way.

Since the ware made on the thrower's wheel and turned in the lathe must be circular, or something approaching it, it is obvious that for the manufacture of rectangular pieces some other method is necessary. There are several such methods, two of the more important being known technically as "pressing" and "casting." In both these processes it is necessary to use molds of plaster, made in such a manner that the clay may be pressed or run into them, to take the form of the mold. For this purpose the mold for any particular piece may have to be made in several parts, held in place in some manner while the pressing or casting is being done, and removed separately when the piece is finished. This would not be necessary for a piece which is wider at the top than at the bottom, but for one that is much "undercut," as in the case of a pitcher, for example, a mold of at least two parts is necessary, and usually there are three. Two of these of equal size and shape form the sides of the vessel, while the third is used for the bottom.

The first operation of the presser in making such a pitcher is that of "batting" the piece of clay he is t use for filling one section of the mold. He does this either with a large mallet, or with an implement very like a rolling-pin, flattening the clay to the thickness required for placing in the mold. For this flattening by mallet or roller the clay is laid upon a block of plaster of Paris and the piece of clay so flattened is known as the "bat." The presser places this bat in the mold, with the surface that has come in contact with the batter laid downward in the mold, and presses it firmly so that it fills every surface and crevice completely. The other half of the mold is treated in the same way, and the two are then joined, and fastened together with a strap passing around them. At the junction of the two sections in the mold, the workman lays long narrow rolls of clay, working them with a sponge and with his fingers until the two sections are united firmly and the seam is entirely obliterated.

Next, a bat of the proper size and thickness is made and pressed into the bottom mold, this being jointed to the two upper half-molds, and the seams effaced, thus completing the pitcher. The mold is then placed in a drying-stove, where the clay hardens and shrinks so that it may be removed from its plaster case without difficulty or danger of breaking.

Meanwhile, another workman, or possibly the same presser, has made the handle for the pitcher by putting a lump of clay of the right size in one-half of the handle mold, and pressing the other half down upon it until all the superfluous clay is expressed. This is also placed in the drying-oven for a short time.

When the pitcher and its handle have reached the right stage of dryness they are removed from their molds and the handle fastened in position by moistening the places of contact with a little slip. If the piece is to be a perfect one after firing, both the handle and the body must be at exactly the same stage of dryness when fastened together, and just the right amount of slip must be applied, too much or too little causing defects. The piece is now ready for the final drying, and firing in the biscuit-oven, to be referred to a little later.

Pieces that are made by "casting" are usually of such shape that they cannot be manipulated conveniently in the molds. In making such pieces, the different parts of the plaster mold are put in place and strapped firmly together. The carefully prepared clay slip is then poured into them until the cavities are filled, just as molten iron is poured into the molds at a foundry. The tendency of the plaster of the mold to absorb the water of the slip causes a thin layer of clay to be deposited against the sides, forming a shell the exact shape of the mold. The thickness can be regulated by the length of time that the slip is left in the mold. In case considerable thickness is wanted, more slip is poured in from time to time until the required thickness is deposited, whereupon the residue is poured off, and the piece dried. In drying it shrinks away from the sides of the mold, facilitating its subsequent removal.

Casting has the advantage of giving pieces of absolutely uniform thickness, and without restriction as to shape. There is great contraction, however, and as pieces so made are very porous there is always danger of crazing in the glazing.

In making pottery by casting, just as in pressing, most pieces are not made entire in the mold. Handles, spouts for teapots, rings for covers, etc., are made separately, and afterward fastened to the wares by men called "handlers," if they work on small pieces, or "stickers-up" if their work is on the larger pieces. Good "sticking-up" requires a thorough knowledge of clay ware, as well as deftness on the part of the workman.

MACHINES THAT MAKE POTTERY

As we have seen, the pottery-makers themselves are largely to blame for the introduction of certain kinds of machines that turned out earthenware much more quickly and economically than could be done by hand. This is not surprising in this age of machinery. The truly surprising thing is that the manufacturers waited so long before discovering that it was possible to substitute machinery for men. That ordinary pottery should pass through the stages of being "wedged" by hand, "batted" with a mallet or rolling-pin, or "pressed" slowly and laboriously into molds, seems incompatible with our ideas of modern progress in the mechanical arts. The potters awoke to a realization of this a little over a quarter of a century ago, at which time machinery for making commercial pottery began rapidly replacing hand-methods.

A few pages back we considered such machines as the blungers, mixing arks, and pug-mills for use in thoroughly mixing the clays ready for the actual process of molding into pottery. Without going into too greatly detailed description, we may consider for a moment some of the other machines that take up the actual process of pottery manufacture, after the clay leaves the pug-mill.

The batting-machine naturally comes first in the order of use. In place of the block of plaster upon which the presser or plate-maker had to pound or roll his clay to the proper thickness for working, an automatic batting-machine is used, which performs the work in a small fraction of the time, and with mathematical accuracy. The essential parts of this machine are a revolving horizontal table on which the lump of clay to be batted is placed, and a tool which descends to the predetermined distance, pressing the clay out into a layer of the required thickness. When it reaches the point in its descent where the distance between it and the revolving bed represents the desired thickness of the bat, an automatic device causes the tool to rise to its original position, leaving the finished bat ready for the workman. With this machine any intelligent boy can do the work of two or three men working by hand.

Machines for making such pieces as plates, cups, saucers, bowls, and similar pieces are called "jolleys." In the simplest form, such as the one used in plate-making, the jolley has a spindle which can be rotated horizontally, and to which the mold is attached. In the case of an ordinary plate or saucer this mold would represent the face, or upper surface, of the dish, and when the bat is pressed upon it the upper surface of the dish is formed. This is then placed upon the revolving spindle, above which is the arm holding the tool for cutting the under surface. This tool is a metal blade, the edge of which represents the outline of one half the bottom surface of the plate. This blade is depressed by means of a handle, and as it descends it cuts off the clay, making a perfect surface and being set so that the lowest point to which it descends represents the desired thickness of the dish.

To run such a machine to its full capacity, the "jiggerer," as the machine workman is called, must have two or three boys as assistants. One of these, who runs the batting-machine, takes a lump of clay, throws it on the plaster head of the batting machine, depresses the lever, and makes a bat of the required thickness. This he throws upon the surface of the mold with sufficient force to expel all air bubbles, and hands the mold with the clay attached to the jiggerer, who fastens it on the head of his machine and sets it revolving by pressing a lever. Moistening the palm of his hand, the jiggerer presses it firmly upon the whirling clay, using sufficient force to cause it to fill the mold completely. If the piece is of somewhat large size he must use considerable force, to do which he presses one hand upon the other. He then cuts off the superfluous clay on the edges, pulls down the cutting tool, and forms the bottom of the piece by steady pressure until the tool will descend no further. Then with a few deft touches he removes any particles of clay that may have been left at the edge of the mold, removes the mold and the molded plate from the machine and hands them to a boy who takes them to the drying-stove. The time required for modeling an ordinary plate in this manner is about thirty seconds.

In making small, hollow pieces on these machines, such as cups, bowls, or round sugar-bowls, the mold represents the outside of the piece, the inside being made with the tool. The batting process is dispensed with, the lump of clay being thrown directly into the mold and formed into the vessel by depressing the cutting-tool at once. In the case of "undercut" pieces—that is, where the opening at the top is smaller than some lower portion—the tool has to be made and set on a movable lever, or some similar device, so that it can cut out and fashion the wider portions of the piece, and still swing back far enough not to touch the narrower portions when it is removed.

From this simple form of plate- or cup-making jolley, all manner of machines have been evolved for making deep and shallow ware, large and small. Some of these are automatic in action, practically dispensing with skilled assistants. As a rule the finer grades of work are not attempted on such machines; but such stock things as cups and bowls, and large pieces, such as wash-bowls, can be turned out with great rapidity. Machines for doing heavy work are found only in the larger potteries, as the mechanism is necessarily complicated, and their initial cost, and the cost of repairs, are correspondingly high.

After the pieces made with these machines are dried and hardened sufficiently to retain their shape, they are removed from the molds and are ready for firing in the biscuit ovens, unless some decoration in clay is to be added. If so, this is done while they are still in the moist state, and by one of half a dozen or more processes. Thus, the impression of small dies on the ware is frequently made by rollers having patterns cut on the edges, which form a continuous pattern when pressed on the ware. Such things as figures, flowers, or other raised designs are made in molds and stuck in place with slip. Facsimiles of lace or textile fabrics are sometimes made by dipping the fabric in slip and applying it to the vessel. During the firing process the fabric is burned away, leaving the impression on the vessel. This process, somewhat modified, is used also for reproducing leaves and other objects.

Perforations in pieces are made either with hollow punches of special design, or with sharp knives. Where much cutting is to be done the workman must exercise great care, as each perforation naturally weakens the clay. This kind of work should not be confused with etching, or carving, on the clay, as such work is done when the ware is fairly dry.

Colored effects and decorations are obtained in a great variety of ways before as well as after the piece is fired. Before firing this is sometimes done with colored clays, or by means of colored slips, or with combinations of the two. These colored slips may be blown through little tubes to form a great variety of figures on the clay, or, if circular stripes or bands are wanted, the piece may be fastened in a lathe, and the bands of colored slip added quickly and evenly. Where the piece has been dipped in colored slip, striking effects can be obtained by cutting it away with a tool, exposing the color of the body of the ware beneath. Thus a very common pattern of fancy bowl, white on the inside and blue on the outside, with white bands encircling it, would be made by dipping the outside clay bowl in blue slip, and then turning off the blue slip in rings in a lathe.

Another method of obtaining striking effects is with the etching-tool after the colored slip has been applied. The tool cuts away the slip, leaving the patterns in the original color of the ware beneath. Indeed, there are endless methods of producing color effects, each manufacturer using combinations and methods of his own. Some of these processes are slow and costly, while others, although effective, are simple and inexpensive, as any one may discover by pricing such wares at a pottery store.

FROM CLAY TO CHINA

Thus far in our story the substance with which we have been dealing has retained its original form as clay, more or less plastic according to the amount of moisture it contains at any particular stage. But whether in the form of liquid slip, as the plastic mass coming from the kneading process of the pug-mill, or as the thoroughly dried dish so hard that it retains its shape perfectly, the substance is still clay, capable of being transformed from one of these conditions to another, simply by moistening or drying as the case may be. But in the next step of pottery manufacture —the one that follows next after the molding, turning, and coloring processes—the plastic substance, clay, is changed into an altogether different substance by the application of intense heat. It can be ground to impalpable fineness, blunged into what appears to be clay slip, and passed through the various processes through which it passed in its journey through the pottery works before being fired; but it will have none of the characteristic plastic qualities of the original clay, nor can pottery of any kind be made from it, any more than can be done with powdered granite or marble. The explanation is that the heat has driven off the "water of combination" as the chemist calls it, and there is no known means of replacing it. This water of combination, it should be understood, is a thing quite apart from the water which is held in suspension in the plastic clay, and which may be driven off by drying. The water of combination is an integral part of the molecule of clay, and remains unchanged whether the clay is in a moist or dry state. No amount of manipulating in the machinery of the pottery affects it in any way until it is brought to a red heat in the biscuit oven. Then it frees itself from its clay associates, and no way is known of inducing it to take up its original relations again. Its leaving causes the body of the clay to shrink, pure clay having so much shrinkage that the potter finds it necessary to counteract the tendency by some substance that does not have molecules containing water of combination. Such a substance is flint; and being very hard and very white, it makes an ideal addition to the pottery mixture.

For firing, the ware is placed in fire-clay boxes called "saggers." These saggers may be of any shape, but the usual forms are either round or oval, saggers of the same size being piled one above another in the biscuit-ovens, resembling somewhat the tall piles of half-bushel measures of vegetables seen in the markets. The saggers are made of fire-clay and a mixture of ground-up biscuit-ware, saggers, and other scraps. They must be very strong and infusible, and able to withstand the repeated heating and cooling processes. The piles of saggers in the oven are known as "bungs."

Filling these saggers with ware and placing them properly in the ovens requires a good deal of skill and much hard labor, as when filled with such flat ware as plates, for example, each sagger weighs from forty to fifty pounds. The workman takes a sagger on his head into the oven, when the pile is higher than his head, climbs a ladder placed for the purpose, and carefully transfers his load to its place in the bung, being careful not to jar or disturb the ware in any way.

Such flat dishes as plates, saucers, soup-plates, etc., are placed one above another in the sagger, from ten to twenty high, according to size. The bottom dish rests on a setter, which may be a thick plate made especially for the purpose, or a suitable piece that has shown some defect after firing. Cups are placed edge to edge one upon the other, to keep them straight; while large dishes of any depth, which are likely to become crooked, are bedded in sand. Pieces having covers, such as sugar-bowls, are fired with the covers in place. If fired separately in different parts of the oven, the variation in heat might cause unequal contraction so that they would no longer fit.

Each sagger as it is placed in the bung forms a cover to the one just beneath. In some potteries sand is rubbed between the joints to make them air-tight, but probably a better method is to "wad" the saggers with clay, thin rolls of fire-clay being placed around the edge of the sagger so that the one next above it, pressing upon the clay, makes the chamber air-tight. The ware in such air-tight saggers must be very dry, however, as otherwise the steam generated and confined in the sagger would "mortar" the ware, which would be found as a shapeless lump of burnt clay when the sagger is opened.

Where the pieces to be fired are of irregular shape, or are too deep to be placed one above another in the saggers, much waste space is left about them. The economical potter, however, is careful to see that all such spaces of any considerable size are utilized. In the deep dishes, such as large bowls, he places smaller dishes; while in other nooks and corners he places all manner of small clay objects. It is a very small space indeed that will not hold such small objects as the many-shaped insulators used by electricians. And as there are from twenty-five hundred to three thousand saggers in the ordinary-sized oven, it will be seen that the number of small objects fired without extra cost may amount to several thousand at each firing.

In this way the pottery manufacturer effects a very great saving, since firing is about the most expensive single item in the process of pottery-making.

Firing consists in raising the temperature of the oven gradually and uniformly to a certain point, usually about 2,500° F. The degree of heat varies for different purposes, but even the very lowest is so high that it takes many hours of firing, and many tons of coal, to reach it in the great sixteen- or twenty-foot ovens. Furthermore, in ovens of that size the variation in temperature in different parts might be enough to "over-fire" and spoil ware in one part of the oven, while in another part the ware would be "under-fired," if the fireman were careless or ignorant, or if he had no way of ascertaining approximately the temperature in every part of his oven at all times.

Of course where such high temperatures are attained the use of ordinary thermometers is out of the question, but the potters have discovered other means of determining the heat of the ovens which are exact enough for practical purposes. An experienced fireman can tell a great deal about the oven temperature by the appearance of the heated interior; but even the most skilful workman does not trust to this test alone unless forced to do so by some accident. Most firemen make use of little rings of clay called "trials" for determining the temperature. These are placed in various parts of the oven, the usual method being to put them into saggers which have holes cut in one side, the opening facing a "trial hole" in the oven. As the firing proceeds the fireman removes a ring through the trial hole from time to time by means of an iron rod, cooling it at once by throwing it into cold water. Knowing the amount of contraction caused by certain temperatures, the coloring effects, the condition of the fractured edge, etc., at the various stages, he is thus able to gage the temperature of his oven. And as the trials are placed in several different positions in the oven he can ascertain easily by comparison whether his oven is being heated evenly.

A more scientific method is to use specially prepared substances that melt at known temperatures. These are made in the form of cones for convenience, and arranged in a graduated series, each of its several cones requiring a different degree of heat for melting. The melting point of the most resistant one represents the necessary degree of heat for properly firing the ware. Such cones are entirely practical, but are more expensive than the trial rings, or trial pieces of clay of various kinds, and for this reason are not in general use for ordinary firing.

In England a gage invented by Wedgwood something like a century ago is extensively used. In this gage the property of heated clay to contract a definite amount at certain temperatures is taken advantage of. The gage is a piece of metal in which is a long groove, tapering from one end to the other, and marked off in degrees. Bits of clay that fit exactly into a definite point in this groove before it is placed in the oven are used. As the temperature is raised the clay bits slide farther and farther along the tapering groove of the gage until their position indicates that the desired degree of heat has been reached.

After the oven has reached the degree of heat required it is allowed to cool slowly until it reaches a temperature low enough for the workmen to enter and remove the saggers. The slower the cooling process the less will be the breakage of ware and saggers, and the time of cooling ranges from two to three days. The ware is then ready for glazing, unless some form of "underglaze" decorating is to be done.

There are several methods of applying this glaze, the preparation of which has been described a few pages back. The most common of these is by "immersion," which, as its name implies, consists in dipping the pieces of ware into a tank having the glaze material held in suspension in water. The density of this glaze must be determined very accurately if good results are to be expected.

When a piece of ware is plunged into the glaze it absorbs a certain amount of moisture at once, leaving a uniform layer of the solid matter of the glaze deposited over every part of it. The time of the immersion, and the consistency of the glaze-mixture, will determine the thickness of the glaze, and this is most important in the final firing of the piece. Pieces of biscuit absorb the glaze in direct proportion to their thickness, the thicker the ware the greater the absorption. All these things must be taken into consideration by the "dipper," as the man who immerses the ware is called.

The general principle of immersing in the glaze is the same for ware of all sizes and shapes, although the actual dipping process differs with various pieces. Deep dishes require somewhat different treatment from such flat pieces as plates, and while this difference is slight, it is enough to warrant confining a workman to dipping one class of ware, once he has become expert in doing it.

In any of the dipping processes, however, the fingers are brought in contact with the piece as little as possible, as otherwise unglazed places corresponding to the finger prints would be left. This difficulty is overcome by moving the fingers constantly during the immersion, and by the use of various mechanical devices, such as metal hooks, whose points of contact with the piece are very small. Thus the plate-dipper often uses a long iron hook shaped to fit the edge of the plate, and attached to his thumb with a strap. He hooks this over the edge of the plate, supporting the opposite edges with his fingers, and passes the plate through the glaze rapidly, taking just the amount of time that he knows by experience is sufficient for the plate to absorb the proper quantity of glaze. Then, with a dexterous jerk, he flings off the superfluous glaze, and the plate is ready for the final firing.

Before going to the oven, however, the piece is inspected by another set of workmen known as "repassers." These men look the plate over carefully to see that there are no places where the glaze is too thick or too thin. If the dipper is a man highly skilled in his work the repassers will find very few such places.

But should they find any, they reinforce the thin spots with glaze applied with a brush, or cut off the excess with a thin, sharp knife.

Another method of applying the glaze is by "sprinkling," which is used for pieces that do not suck up the glaze readily, or on those whose interior surface is to be glazed a different color from the outside. In such pieces the outside is dipped in the ordinary way, the glaze for the inside being introduced by a spoon, or ladle, which is then run around so as to cover all the surface, the excess being poured out.

Glazing by volatilization or "smearing," as it is called, is a process by which the glaze is applied while the ware is still in the biscuit-oven. In this process the saggers are either left open, or the glaze to be volatilized is placed in a cup in each sagger. As this volatilizes it combines with the silica in the ware, forming a coating over it. This method is used for pieces with sharp outlines which might otherwise be filled or rounded by the dipping process. So-called stoneware is glazed by throwing salt into the oven when it is well heated, and as this volatilizes it combines with the silica in the ware to form the glaze.

Very cheap ware is sometimes glazed by dusting dry powdered glaze over the ware while it is still damp enough to hold it. Only one firing is then required to finish the piece. Such ware is of very inferior quality, and the process is very hurtful to the workmen who breathe the air loaded with the fine particles of the glaze, some of which are of a very injurious composition.

The placing of the ware in the glaze-kiln, or "glost-oven," as the oven for firing the glaze is called, is a much more delicate operation than placing it in the biscuit-oven. In the biscuit-oven many dishes may be piled one above another, each resting on the one beneath, and coming in contact with it. But in the glaze-kiln, where the glaze becomes a sticky layer of molten glass covering every portion of the ware, this cannot be done, as every point of contact will show in the finished ware. If plates, for example, were piled together, as they are in biscuit-firing, they would be welded together into a solid mass. It is necessary, therefore, to support every piece of ware on just as few points of contact as possible, and have those points as small as practicable.

The ideal way of placing the ware would be to have it suspended in such a manner that no portion of it came in contact with anything. As this is obviously impossible, the potter must be content with some device that makes the necessary points of contact as few and as small as possible. By means of variously shaped bits of burnt clay, known as thimbles, spurs, stilts, saddles, etc., he arranges his ware so that the points of contact show very little in the finished ware—so little, indeed, that in the best pieces only the eye of an expert can detect them. To do this requires great ingenuity, especially as in doing so the utilization of every possible inch of space in the saggers, for economy's sake, must be borne in mind.

For pieces of unusual shape, or delicacy, the placer has often to devise supports of special form and construction; but for standard pieces, such as plates, cups, or saucers, there are several well-known methods that economize both time and space. Thus, plates may be placed horizontally one above another in the sagger by the use of little pieces called "thimbles," three thimbles to each plate. The thimble is a little piece of fired clay shaped like a thimble, as the name implies, but having a little spur, or projection, on one side, which comes in contact with the edge and back of the plate it supports. Three of these are placed in the holes of the frame or ring made to receive them, the triangle thus formed being of exactly the right size so that a plate to be glazed rests against the little projections on the thimbles without touching anything else. Three more thimbles are then fitted into the first three, and another plate placed on them, and this process repeated until the stack is high enough to fill the sagger. A ring, with three projections that fit into the three upper thimbles, is then placed on the top, binding the whole firmly together. Plates so placed are said to be "dottled," and this is the method used in most factories for placing the best grade of ware.

Another method is to use a combination of thimbles and saddles for supporting the plates vertically in the sagger. Saddles are long, triangular pieces of fired clay. Two of these are laid parallel in the bottom of the sagger at such a distance from each other that a plate placed vertically rests on their upturned edges without touching at any other point. A thimble is used at the top of each plate, making the third point of support, each thimble socketed into its neighbor to form a line at the top that binds all the plates together. By this method of placing, two small marks are left on the edge of each plate where it comes in contact with the saddles, and a third mark where it touches the projection on the thimble.

These are only two of the many methods of "placing" ware whose shape permits of several pieces being placed in the same sagger. The very best results in glazing are obtained by placing each piece of ware in a sagger by itself, but of course only the most expensive ware is fired in this way, and even in such sets the flat pieces are fired together.

Firing the glaze-kiln is a somewhat shorter process than that of firing the biscuit-oven, as a rule. The temperature is not raised to quite the same degree, as otherwise the body of the ware might be affected. The time required may be said roughly to be from sixteen to twenty-four hours, and the temperature attained about 1900° F. The quicker the oven can be brought to the required heat the better and brighter will be the glaze.

DECORATING THE WARE

We have seen that certain kinds of decorations and coloring are done, while the ware is still in the clay state, by the use of colored clays and colored slips. But the two periods in the manufacture for doing most of the decorating are after the ware has been fired in the biscuit-oven before the glaze is applied, and after the final glazing has been done. The first of these is called "underglaze" decorating, the second "overglaze." The underglaze decorating is the more permanent, and more generally used, while the overglaze decorating has the advantage of lending itself to a wider range of color and design.

The methods of underglaze decorating are as widely diversified as those of the art of picture-making. They range from the crude outlines drawn with a stick, such as those of the Arizona cliff-dweller's pottery, to works of art requiring fine brush-work, copper plates, and printing-presses. Indeed, the printing-press and engraved plates have played almost as great a part in the production of cheap and beautiful pottery as they have in the production of cheap books. And as in the case of making books, they enable endless numbers of the same elaborate designs to be made at very small cost.

It should not be understood, however, that the printing-press of the potter has reached any such stage of development as that of the book-maker's press, in which a piece of paper is converted into a folded book, and duplicated at the rate of many thousand per hour. Such machines, or machines aiming in that direction, have been attempted with some degree of success, but the most practical machines at present are still in the stage of development corresponding to the earliest type of printing-press, where most of the work depended on manual dexterity.

The first step in the process of china-printing is that of engraving the design upon a copper plate. This may be done with acids, or by means of steel tools.

With either process the engraving must be of sufficient depth to retain the requisite amount of color in transferring to the ware. In using this plate the printer first places it on a steam-heated stove which keeps it at that temperature which allows the working of the colors to the best advantage. Then he cuts a piece of specially prepared tissue-paper, in size somewhat larger than the engraved design on the copper plate, and "sizes" it by brushing it over with a solution of soap and soda. He lays this aside for a moment while he smears his color over the engraved part of the plate, with a thin knife, afterward rubbing the color into every line of the design with a wooden rubber. Any excess of color is removed with the knife, and the surface of the plate finally cleaned with a corduroy boss. Next he places the piece of wet paper over the color-filled engraving, and transfers the plate to the press.

The press is composed simply of two iron cylinders, set horizontally and parallel, with a bed or table that runs back and forth between them. The upper cylinder is covered with several layers of soft cloth. The printer places the copper plate on the bed of the press, pulls the lever that makes the cylinders revolve, and runs the table between them. As the table passes forward the padded upper cylinder presses the paper firmly against the copper plate, causing it to take up every particle of color from the grooves of the engraving beneath. The pressure against the hot plate also dries the paper completely, so that it may be lifted from the copper surface, bringing the color with it. It may then be transferred to the ware by simply pressing it upon the surface and rubbing it thoroughly, first with a soft cloth, and then with a rubber dipped in soap if the surface of the dish is level, or with a brush if uneven. The ware absorbs the color almost immediately, and the paper may then be washed off without danger of injuring the pattern beneath. If the ware is very hard, and consequently somewhat less absorbent, this washing-off process is delayed a few hours, after which the dish is sent to an oven where every particle of moisture and oil from the color is driven off. It is then ready for glazing.

The process of printing just described is the simplest, but also one of the most useful, used in the manufacture of pottery on a large scale. There are many modifications of it, such as having the figures engraved on cylinders which on revolving print the figures in succession, but the general principle is the same as with the flat process.

This underglaze method of printing colored designs is frequently combined with hand-painting, and in this manner elaborate color schemes may be used, though the number is still restricted to those that will withstand the heat of the glaze-kiln. In this combination process the designs may be printed simply in outline, the figures being filled in with brushes.

Dishes of circular form may be striped with colors by means of small pencils or brushes, the workman using a small turntable on which he centers the piece accurately. Stripes can then be placed uniformly and quickly by holding the brush steadily in one position.

The limitations placed upon underglaze decorations, on account of the action of the glaze-firing that follows, are practically eliminated in the process of overglaze decoration. The degree of heat necessary to fix the colors applied over the glaze is much less than that of the glaze-kiln, and the effect upon the colors very slight, and so well understood, that the decorator has practically unlimited scope both as to color scheme and design. Real works of art, comparing favorably with those painted on canvas, with every degree of delicacy of tint, have been made, and are still being made, in great numbers, on chinaware. The colors are more permanently fixed than those on canvas, or any other material—in fact, are practically indestructible except by breakage of the ware. With dishes in daily use, to be sure, the colors do eventually lose their brilliancy, and finally wear off; but this is due solely to constant and hard usage. Potters, however, prefer the underglaze decoration as a rule, claiming that the depth of tone in pieces thus painted more than offsets the variety of colors. But they find a combination of the two processes very useful, particularly in expensive pieces where the underglaze design has not come out well in all places. Where such defects are found the pieces can be touched up after the glost-firing, fired in the enamel kiln, and made perfect.

The metals supply most of the colors used in china decoration, although there are some earths used for certain purposes. Not all the metallic colors, however, will withstand the heat of the glost-oven; and such colors can only be used for overglaze decoration. Gold and copper give two such colors. The gold is used to produce rose and purples. Copper makes a green, the various shades being produced by the addition of blue or yellow. Red is made from iron oxide, brown from iron chromate, blue from cobalt, white from tin, and yellow from antimony. Besides these there are great numbers of fundamental-color combinations used, so that the china-painter has almost as wide a range in his choice of pigments as the artist who works on canvas.

XI

GLASS AND GLASS-MAKING

"THE making of glass originated in fairyland," says a learned historian of art—which is a graceful way of admitting that the origin of glass-making is unknown. But certainly this valuable discovery was made at the very dawn of civilization. We cannot point to a definite "glass age" as we can to a "stone age" or a "bronze age"; but considering the manifold uses of glass we may be inclined to agree with the enthusiast who maintains that the "glass age" is commensurate with civilization; that without glass, indeed, there would be no advanced modern civilization.

At the present time it can be truthfully said that our civilization is largely dependent upon the single form of glass used for house-lighting. There could be no great northern cities like New York, London, or Berlin, without window panes. But the part played by glass in other forms as an aid to science and mechanics has been quite as important as in the field of lighting. It was the glass prism that enabled Newton to discover the composition of light, and develop the science of optics. Without this same prism the spectroscope would never have been invented—that marvelous instrument which discovers a substance millions of miles away in the sun, even before the same substance is found on the earth, and helps in a hundred equally wonderful ways to make possible the modern science of physics. In the form of lenses, glass has enabled men to solve some of the riddles of the firmament—to detect a sun-spot and predict with some certainty a famine in India from its effects, or to foretell the coming of a comet or an eclipse. The same lenses, combined somewhat differently in the form of the compound microscope, throw open to man that other world, whose minute inhabitants influence the destinies of man and races much more than all the savage beasts and savage men have done throughout the ages.

Scarcely less in importance are the revolutionary effects of glass when applied as man's direct helper in the form of spectacles. Imagine for a moment what would become of this reading, print-devouring world to-day, without glass. Abolish lenses, and a large proportion of men and women over fifty years of age would be unable to read ordinary books, newspapers, and correspondence. Another vast army of persons who suffer from astigmatism would be condemned either to perpetual headaches, or to abandon reading and writing after the age of thirty or thereabouts. While still another army of children who suffer from congenital optical defects, that even in childhood must be corrected by glasses, would never be able to learn to read and write at all.

In the discovery of electricity and in nearly every phase of the development of electrical science, glass has played an important part. For years the only known method of generating electricity in any quantity was by means of rubbed glass; and when this electricity had been generated, glass was the substance that made possible its isolation and distribution. There would be no Edison incandescent light to-day; no wonderful Hewitt mercury-vapor light, and no X-ray, but for glass.

These are only a few of the more important developments that glass has made possible; and all things considered, then, it is little wonder that glass has been looked upon as a gift of the fairies.

But if fairies are responsible for the secret of glass-making, to whom was this secret first imparted?

Pliny says that some Phœnician merchants were the favored ones. According to his story a band of these merchants having landed on the sandy bank of the river Belus, in Palestine, to prepare a meal, and being unable to secure stones for supporting their cooking-pots, used blocks of niter taken from the cargo of their boats. The heat of the fire caused a fusing of the niter and the sand, which resulted in the production of glass.

Josephus credits the Children of Israel with the discovery of glass in a more spectacular, if quite as accidental, manner. Some Israelites, he says, once set fire to a thick forest that happened to be situated on a hillside of sand heavily charged with niter. The intense heat of the burning forest caused the niter and sand to fuse and run down in streams of molten glass, which hardened in pools at the foot of the hill. Observing this wonderful phenomenon the Israelites set about fathoming the secret, and, with persistence characteristic of their race, succeeded.

But cold modern science points out that glass could not have been formed by either of these fantastic processes. Neither the open fire of the Phœnicians nor the forest fire of the Israelites would have produced sufficient heat to fuse the materials into glass, even if they had been present in the earth. Furthermore, the archæologist delving into the sacred vaults of ancient Egypt, brings forth pieces of glass that were in existence hundreds, perhaps thousands, of years before the time of the Phœnician merchants of Pliny or the Israelites of Josephus. And, as if in anticipation of some dispute as to the question of their antiquity, some of these pieces of glass in the forms of beads worn by a princess of an ancient dynasty have the name of the royal wearer engraved on each bead. It is certain that glass was in use in Egypt six thousand years ago, and in Babylonia even before that, but further than this it is all a matter of conjecture. As to the manner of its discovery, the most probable conjecture is that it was the result of some accident in the making of brick or pottery, of which art both the Egyptians and Babylonians were masters.

Such articles as glass beads and ornaments, and very probably certain useful utensils, were made from glass long before window glass was introduced. By the time of the Greeks and Romans, glass-work of all kinds, some of it extremely delicate and beautiful, was in common use; and it is by no means certain that looking-glasses and window panes were not invented even at this early period. The glass mirror is supposed to be a comparatively modern invention, but it is quite possible that such objects were known to the ancients and then forgotten during the retrogressive days of the Dark Ages.

In the case of window glass this very thing seems to have occurred. For years the question of the antiquity of the window pane was a mooted one between scientists and antiquaries. "Suddenly antiquity herself, tired doubtless of a discussion that threatened her own honor," says Sauzey, "decided the question by proving that she possessed window glass. And, indeed, the researches near Pompeii have brought to light panes of glass which have remained fastened to their frames more than seventeen hundred years under ashes."

A DOUBTFUL ROMAN TRADITION

This discovery confirms the belief that the Romans had become skilful glass-workers even at a very early period. Indeed, judging from some of the Roman tales, the artisans were not only familiar with ordinary glass-working, but were attempting to discover a process whereby glass could be made malleable—a desideratum that is still vainly sought. One of these stories tells of a workman who succeeded in solving the problem, with dire consequences to himself when he exhibited his discovery to the Emperor Tiberius.

"There was once an artist who made vessels of such firmness that you could no more break them than gold or silver," runs the story. "This person, having made a cup of the finest crystal, and such a one as he thought worthy none but Cæsar, got admission with his present. The beauty of the gift and the hand of the workman were highly commended, and the zeal of the donor kindly received. When the man, that he might change the admiration of the court into astonishment and ingratiate himself still more into favor of the emperor, begged the cup out of Cæsar's hand and dashed it against the pavement with such vehemence that the most solid and constant metal could not escape unhurt, Cæsar was both surprised and hurt at the action; but the other, snatching the cup from the ground, which was not broken but only a little bulged as if the substance of metal had assumed the likeness of glass, drew a hammer out of his bosom and very dexterously beat out the bruise, as if he had been hammering a brass kettle. And now the fellow was wrapt in the third heaven, having, as he imagined, got the friendship of Cæsar and the admiration of all the world; but it happened quite contrary to his expectations. For Cæsar asking him if anyone knew how to make glass malleable besides himself, and he answering in the negative, the emperor commanded his head to be struck off; for, said he, 'if this art be once propagated, gold and silver will be no more valuable than dirt.'"

It seems incredible that the use of glass for window panes should have been forgotten once it had been discovered; yet this appears to have occurred during the Dark Ages. Window glass, which "lengthens life by introducing light into dwellings," entirely disappeared during those centuries when so very many of the essentials of progress, to say nothing of comfort, were forgotten. In the place of glass, primitive wooden shutters were used in the poorer class of dwellings; while in the better class, transparent stones, oiled paper, and skins were made to take the place of glazing.

Even as late as the fifteenth century panes of window glass were seen only in the dwellings of the wealthy. Among the records of the brilliant court of the dukes of Burgundy is an order, dated 1467, which calls for "twenty pieces of wood to make frames for paper, serving as chamber windows." And even a century later, glass windows were so much of a luxury and so expensive that we find the steward of the Duke of Northumberland ordering that the lights of glass in the castle be "taken out and put in safety when his Grace leaves. And if at any time his Grace or others should live at any of the said places, they can be put in again without much expense; whilst as it is at present, the destruction would be very costly, and would demand great repairs."

By the eighteenth century, window glass had become common enough so that even the dwellings of people in moderate circumstances were fitted with small panes—small indeed, and so unevenly made that objects seen through them were distorted into fantastic shapes—but nevertheless light-giving window panes. Small panes of good quality were obtainable at fabulous cost, to be sure, but it was not until late in the nineteenth century that plate glass in great sheets was manufactured, and brought within the reach of the generality of people.

THE COMPOSITION OF GLASS

As is well known, silica is the chief component of glass, and the mixture of this substance with other substances in certain proportions determines the kind of glass produced. "Potash or soda and lime are mixed with the silica to obtain *window* or *plate* glass," says Cochin; "add oxide of iron and you have *bottle* glass; substitute oxide of lead and you obtain *crystal;* replace by oxide of tin and you produce *enamel.* The union of the fusible bases, lime, alumina, magnesia, produce infusible compounds; but combined with fusible and infusible bases, the silicic acid forms multiple silicates which melt very readily. Plate glass is precisely one of these mixtures of three elements. It is composed of silica, soda, and lime,—in the proportion of silica 73, soda 12, and lime 15 parts.

"Silica exists everywhere. Rock-crystal, sandstone, sand, flint, are composed of silica; it is also found in the ashes of plants, volcanic streams, and mineral springs. Sugar resembles glass, and this likeness is not deceptive. Melt the ashes of sugar-cane, and you have glass; for with the silica they contain both potash and lime.

"Calcareous substances compose perhaps one-half the crust of the globe. Lime is in our bones; it is also in vegetables and straw, in the human skeleton and common earth; it is found everywhere—even more widely distributed than silica.

"Soda also is found in nature. It has long been obtained by combustion of certain marine plants; in the present day it is produced very easily by artificial means. Potash may be employed instead of soda; it is not less common and widely known; it exists in all ashes.

"Here then we have the key to all those profound mysteries of Murano, Bohemia, and St. Gobain. A mirror is a valuable object produced from the commonest materials. To assist the memory, let me thus sum up the preceding remarks. When warming your feet, if you look at yourself in the mirror, remember that the mirror which adorns your mantelpiece can be manufactured by the help of that same mantelpiece and fireplace beneath: the stones furnish the silica, the ashes the potash, the marble the lime, and the fire is the only mysterious agent required for the transformation. 'Glass,' according to the old saying, 'is the offspring of fire.'"

The predominating silicate used frequently determines the name of the product. The terms "soda glass," "lime glass," etc., indicate that the soda or lime silicates predominate over the other silicates present in a particular glass. Most of the ancient glass was soda glass, but the later Venetian glass contained potassium and calcium in considerable quantities. Bohemian glass contains the silicates of potassium and calcium. Flint glass is a mixture of the silicates of potassium and lead. Bottle glass is usually a mixture of the silicates of calcium, aluminum, and sodium.

The different silicates impart certain definite qualities to the glass. For example, sodium silicate gives the glass a greenish tint; potassium silicate adds to the brilliancy and fusibility of the glass; and lead silicate increases the ductility, as well as the fusibility and brilliancy of the product. An excess of lime renders the glass too brittle for practical purposes.

Since sand is the principal source of the silica used in glass-making, it is this substance which comes in for closest scrutiny and most careful examination in the preliminary preparations of glass-making. Generally speaking, the quality of the sand determines the quality of the product, and as all sand contains many injurious impurities, a course of preliminary preparation and purification is necessary before it is used. This preparation consists of the various processes of washing, burning, and sifting. In the process of washing, the heavier grains of pure sand settle to the bottom, while many of the lighter impurities float at the surface where they may be skimmed off. The burning removes the moisture and destroys whatever organic matter may be clinging to the sand grains, while the final process of sifting through copper gauze reduces the grains to uniform size, and removes, besides, the impurities still further.

By far the most troublesome impurity found in sand—one that can be neither sifted, burned, nor washed out—is iron. Indeed, this substance is so troublesome that sands containing large quantities of iron are not suitable for glass-making, and the value of any sand is determined largely by the amount of this impurity it contains.

One reason for the large amount of inferior glass manufactured in former years was the fact that so little care was taken in properly apportioning the different ingredients, the mixing being largely a matter of guess-work. But in the modern glass-factory this haphazard method has entirely disappeared. The exact chemical constituents of each ingredient are determined by analysis, and the proportions adjusted to a nicety, with the result that there is now a great uniformity in the product.

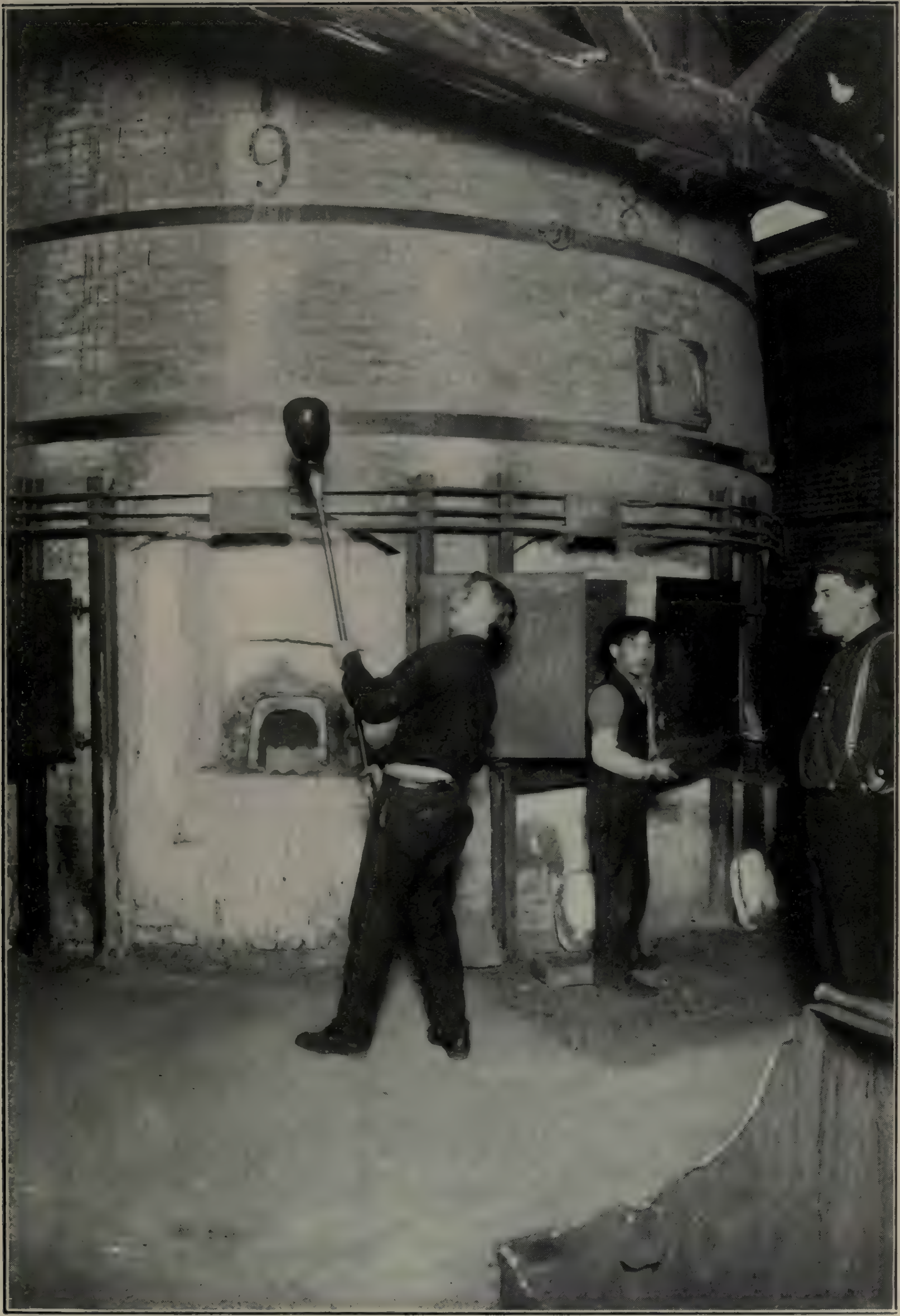
As we have seen, when the various ingredients are mixed together and brought to a certain temperature, liquid glass results,—a sirupy substance resembling very thick molasses. Pouring this liquid upon some flat surface in a thin layer and allowing it to cool, would seem to be the easiest and most natural method of making such flat sheets as window glass. And, indeed, such a method is the one now used for making the superior quality of window glass, or plate glass. This is not the method, however, by which glass of inferior quality is manufactured. Ordinary window glass, for example, is blown first into hollow cylinders, then smoothed and flattened out. This process is a much more picturesque one than that used in making plate glass, although the product is greatly inferior.

THE PROCESS OF MANUFACTURING WINDOW GLASS

The mixture of soda, lime, and silica that is to be melted and transformed into glass is technically known as the "batch." The melting and transforming processes are slow and tedious ones consuming many hours, and requiring great skill and judgment on the part of the master-melter. As a first stage of the process the melting-pots—"monkey pots," as they are called—are filled with the batch and heated until the contents melt. This requires several hours, and when accomplished the shrunken bulk is increased with fresh shoveling of sand, and this melted in turn, until the pots are almost full of the liquid. As a finishing touch a small shoveling of "cullet," or broken glass, is thrown in and melted—a dash of flavoring to the brew, so to speak.

All this time the master-melter has been crowding his fires to their limit, meanwhile keeping a watchful eye on the condition of the melting mass. Fourteen, sixteen, even twenty or more hours he must wait before the liquid attains the right consistency. Then gradually the fires are lowered, and the temperature of the molten glass reduced until it is a little thicker than thick molasses—the consistency of tar on a hot day—which is the ideal condition for manipulation by the blowers. This finishes the work of the master-melter. Now different sets of trained workmen take charge of the contents of the monkey pots.

The first of these is the gatherer, who dips out a certain quantity of the hot, gummy glass on the end of the long blowpipes. The position of this workman is a most trying one, as he must be constantly in close proximity to the blistering heat of the furnaces. To protect himself he wears a kind of shield or mask held in his teeth in front of his face. With hands protected by coarse gloves, he dips the end of the blowpipe into



"GATHERING" GLASS.

The dark, pear-shaped mass which the workman is holding up is molten glass which he has just taken from the melting pot on the end of the blow-pipe.

the pot, skilfully turning and twisting it, and bringing out a mass, ranging in weight from twenty to forty pounds, clinging to the end, which represents a future pane of glass of definite size and thickness. This he twists and turns in an iron mold until it assumes a perfect pear shape, passing it on at once to the blower—the master-workman of the establishment, whose task is at once picturesque and laborious.

Skill alone, which on the one hand is absolutely essential, is not the only requirement in the make-up of a master glass-blower. Obviously the man who is to swing and turn a forty-pound mass at the end of an iron rod continuously for many minutes, exhausting himself still further meanwhile by repeatedly blowing quantities of air into the mass, not pausing until a great, hollow cylinder is produced, must have muscle and endurance far above the average. For this reason good blowers are almost always in demand.

In blowing these long cylinders, the workmen stand over deep pits dug in the floor of the room. "The workman at first blows lightly," says M. Peligot, "drawing out the vitreous mass a little, so as to give it the form of a pear; he balances his rod, then raises it so as to gather the glass. He afterward blows harder at short intervals, and gives it a movement backward and forward like the clapper of a bell, so as to strengthen the pear, which assumes a cylindrical form. He raises it rapidly over his head, then gives it a complete and rapid rotary movement, in order to lengthen it, while giving it an equal thickness in every part.

"When the cylinder is made, the blower brings it back to the open furnace so as to soften the end. When it is sufficiently hot it is pierced with an open point. By the balancing movement this opening is increased; the glass is pared with a sort of wooden plate; the edges separate and the top of the cylinder disappears.

"When the cylinder has become firm, it is placed on a wooden rest. The end of the pipe is touched with a cold rod; it separates immediately from the cylinder, which has already lost its bullion point, when a thread of hot glass is wound around it, and the part thus heated is touched with a cold iron rod. Thus we have now on the rest a cylinder open at each end. It is opened by passing a red-hot iron rod down the interior in a straight line; one of the heated extremities being wetted with the finger, the glass bursts open. The same result may be obtained by using a diamond attached to a long handle, which is passed down the interior of the cylinder by the side of a wooden ruler. This method gives a straighter cut, and consequently involves less loss."

Each of these cylinders is to form a perfectly flat pane of glass, for which purpose it must be heated in the flattening-oven. In this oven it is placed on a flat slab, which is covered with some such substance as gypsum to prevent adhesion. The natural effect of the heat is to cause the cylinder to unroll, a workman assisting this process by gentle pressure with a pole. When it has become completely flattened the ovens are hermetically sealed, and the annealing process, which will be explained in a moment, begins.

GLASS-BLOWING.

The workman is blowing a glass bottle of predetermined size and shape in a mold.

PLATE-GLASS MAKING

In the process of making plate glass, the last vestige of picturesqueness, as seen in the older glass-blowing establishments, is removed. Here there is no use for the sturdy gatherer protecting his face with the mask held in his teeth, nor for the muscular blower. Science and mechanics have found better substitutes for brawn and muscle in the form of machinery; and, as in so many other cases, produce a superior product to that made by manual labor.

Plate-glass making is simply a kind of casting, very similar to the casting of ordinary metals. The glass is first melted and then poured upon a flat surface, rolled to a certain thickness and allowed to cool. When cool it is ground and polished.

Naturally, the materials for making plate glass must be carefully selected. Only the finest quality of white quartzose sand is used, mixed with such other substances as carbonate of soda, slaked lime, manganese peroxide, and "cullet" in definite proportions. When these are melted and brought to the proper consistency, the molten mass is poured at once upon the molding-plate, as the casting-table is called. For some of the coarser kinds of plate glass, where translucency rather than transparency is desired, the liquid is ladled out in large malleable iron ladles. But by this process air bubbles are introduced, rendering the glass unfit for polishing.

The casting-table is a thick, cast-iron plate, over which is suspended a heavy iron roller, so arranged that it can be set at any desired distance above the table-plate. When the molten glass is poured upon the table, it is rolled to the proper thickness and distributed evenly, by passing this roller over it—just as a baker uses a rolling-pin for flattening his dough. In this case, however, the roller is worked by machinery.

The moment the rolling is completed, the plate is transferred to the annealing-oven. From this it emerges as "rough plate" ready for grinding and polishing. This is done by cementing the plate to a huge revolving table by means of plaster of Paris, and then grinding it, first with coarse emery paper, and then gradually with finer powder until the surface is even and smooth. The final polish is then given it, either by hand or by mechanical rubbers made of felt and moistened with a solution of peroxide of iron. These various processes of grinding and polishing reduce the original thickness of the plate by about forty per cent.

The most vital and important part of glass-making, next to the actual fusing of the metals, is the annealing. This is simply a process of slow cooling after the glass has been molded into shape—a tempering process, like the tempering of steel. If allowed to cool in the open air at the ordinary temperatures, the pores at the surface of the glass would close more quickly than those deeper in, and a brittle, fragile product would result. To avoid this, ovens with gradually diminishing temperatures are used, the cooling or annealing process sometimes occupying several weeks.

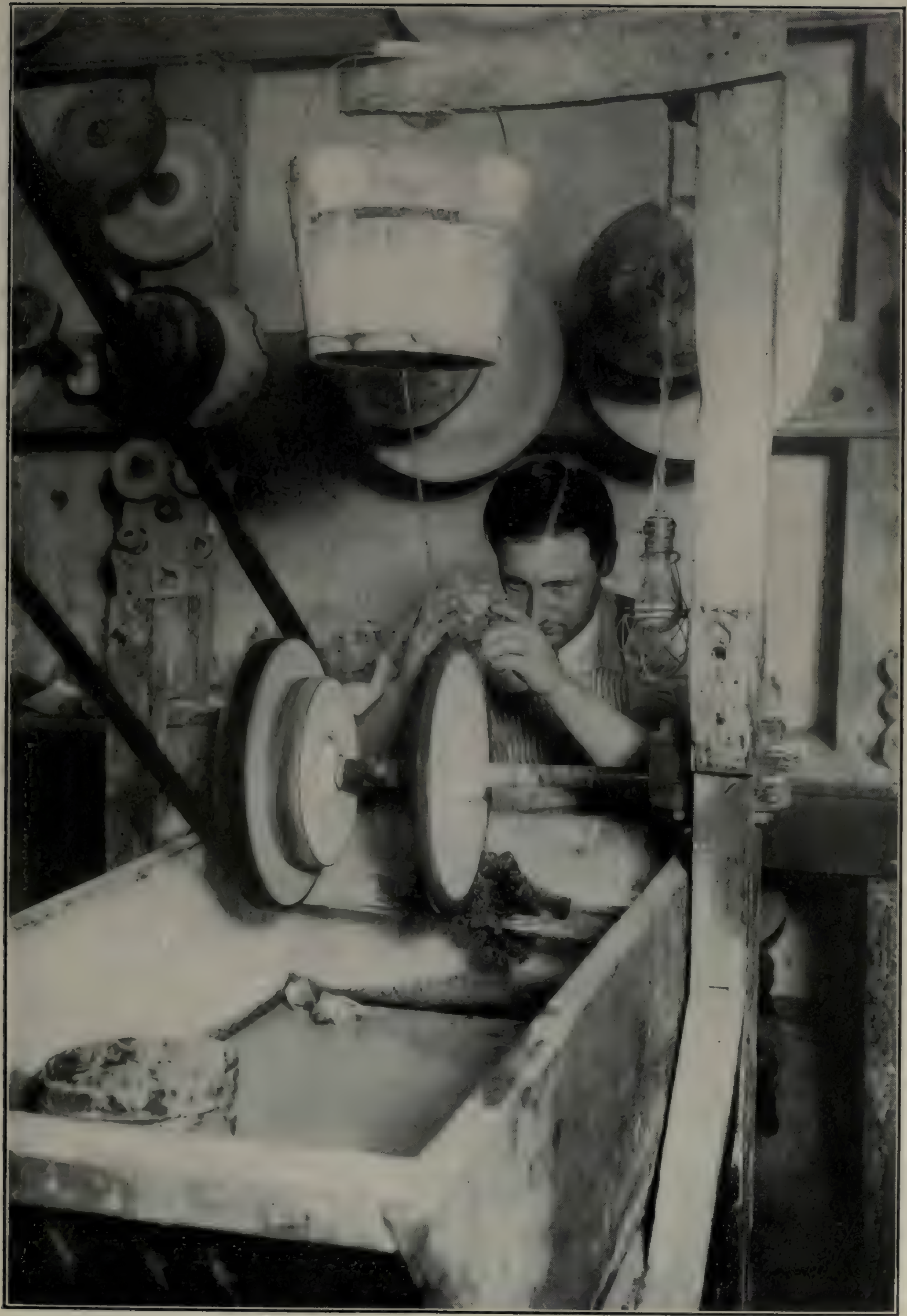
The ordinary annealing-oven is so arranged with draughts of hot and cold air that the temperature can be maintained indefinitely at any desired degree, or cooled gradually to that of the surrounding atmosphere. There is another and more recent type of oven, however, known as the "lehr," made in the form of a tunnel some two hundred feet in length. The heating of this long tunnel is done mostly at one end, the temperature diminishing gradually and uniformly toward the other end. Running the length of this is an endless-chain arrangement, on which the plates are passed from the heated extremity to the cooler one, being timed so that a single passage through the lehr completes the annealing. In such ovens, which are becoming rapidly popular, particularly in America, the time required for annealing is reduced from days to hours.

Aside from window glass, and coarse bottle glass, glass used for most purposes is flint glass. French "crystal" is the same as English flint, and this glass is distinguished by its weight and brilliancy. Cut glass, optical glass, and all the best blown and pressed glassware for houshold use is of this material.

In working this glass, all three methods of working—blowing, pressing, and molding—are used. Cut glass is first blown roughly into the desired shape in the open air, and then subjected to the cutting process. It could be cut after being molded instead of blown, but such glass lacks something of the brilliant luster of glass blown in the air. The cutting is done on grindstones moistened by streams of wet sand, and by emery wheels, the finest polish being given by putty powder.

Pressed glass, which, like cut glass, is a highly developed American product, is made by pressing the molten glass in molds. It is a form of casting, and can be done so cheaply that it has become very popular. The shapes and patterns can be made closely to imitate cut glass—lacking something, however, of the sharpness of angles of the genuine article.

A recent innovation in glass-making is the now familiar "wire-glass" used for skylights, roofs, and entrances where translucency and strength are desired rather than transparency. It can also be made practically transparent and as such is now much employed in the windows of office buildings, warehouses and factories. In such glass a strong wire netting is incorporated in the glass. This wire prevents the falling of huge fragments of glass when the pane is fractured, as is frequently the case with plate glass. It acts admirably also as a fire-screen, the wire holding the glass in position even when heated sufficiently to become plastic. This glass was patented by Frank Schuman, an American, in 1892; and since that time it has grown steadily in popularity.



GLASS-CUTTING.

The cutting is done on an emery wheel or on a grindstone, to which sand, emery-powder, or some similar abrasive is applied.

XII

GEMS, NATURAL AND ARTIFICIAL

"IF you will escape the evil effects of drunkenness, be preserved from hailstones and locusts, sleep well, and not be troubled by evil spirits of witches," says the medieval sage, "suspend an amethyst bead on a hair from a baboon and wear it at the neck."

There was a time when many people believed such things as this. We of the enlightened twentieth century do not. And yet, much as we should like to deny it, there are persons even to-day who have not quite escaped the Dark-Age superstition—the superstition handed down from Egypt, through Greece and Rome—that there are "lucky" and "unlucky" gem stones. What real difference is there, after all, between the half-spoken belief that the opal is an "unlucky" stone, and the sage's statement that the amethyst is a "lucky" one, except in the matter of specific wording as to just what evils are to be averted in the one case, as against a general statement in the other? Most of us, to be sure, do not believe in the general or the specific statement any more than we believe that it really matters whether we see the new moon over our right or our left shoulder. Yet there are persons who still prefer to catch the first glimpse of the new crescent "over the sword arm"; and popular prejudice against the opal is still sufficient to deprive that gem of a popularity that is warranted by its beauty and pleasing qualities.

A few years ago a financier who had suffered great business reverses, as well as deaths in his family, brought his "opal" ring to a jeweler and offered to sell it, having become convinced that wearing the ring with its unlucky stone was the cause of his misfortunes. The jeweler, after examining the ring, smilingly informed the stricken financier that the stone was not an opal, but a star-stone—and not supposed to be unlucky at all.

Fully to understand how deeply rooted an inheritance is any superstition about gems, it must be remembered that for ages and ages, from the most remote periods in history until well into the middle of the present era, gems were valued quite as much for their occult powers as for their beauty. The amethyst, as we have seen, was believed to be a lucky talisman. The chrysolite and the topaz possessed the power of "cooling boiling water, and quieting angry passions." If placed in a vessel containing poison the gem lost its luster, but its brilliancy was unimpaired if no poison were present. It may be surmised that chrysolite and topaz were favorite gems with certain unpopular persons in olden times.

But after all it was unnecessary to take the trouble to test suspected concoctions with a topaz if one were wearing a ruby or a diamond, as these gems protected the wearer against all poisons. Yet the diamond itself was thought to be a deadly poison. Benvenuto Cellini tells in all seriousness of an attempt to poison him by placing diamond dust in his salad. Fortunately, he says, the "gem" from which the powder was made was a spurious one, and so he suffered no evil effects.

Besides counteracting the effects of poisons the diamond possessed many other magic powers. It deprived the lodestone of its magnetism, and had marvelous power against lightning—merely touching the corner-stone of a building with a diamond insured the structure against Jove's destructive bolts. If held in the mouth it caused the teeth to drop out; but if worn on the finger it engendered courage, virtue, and magnanimity in the wearer. It was a good partisan in case of lawsuits, influencing both judge and jury in the wearer's favor. In this last connection it would seem that the diamond has not entirely lost its power.

Some of these qualities were shared by the ruby, which possessed the additional power of warning its wearer of impending danger by turning black. For detecting false witnesses an emerald was most efficient. When brought into the presence of such a witness the stone exposed his falsity by "undergoing some extraordinary change." If one desired to be "rich, wise, and honorable" a jacinth should be worn in a finger-ring. The jacinth was a very popular gem.

CONFUSED NOMENCLATURE

The danger of putting absolute faith in these remarkable qualities of gems, and the loop-hole for explanation in case of failure, lay in the great confusion in their nomenclature which existed all through ancient and medieval times, and which is still very far from being overcome. The diamond is sometimes blue in color, and occasionally the sapphire is white; and as there were no absolutely certain tests until modern times, there was always the chance of wearing the wrong gem inadvertently.

To straighten out this confused nomenclature, which is entirely lacking in anything approaching systematic arrangement, is one of the first problems to be mastered by the student of precious stones.

"Gems seem to have acquired their names quite irrespectively of any system of nomenclature," says Claremont, "and with an utter disregard to their relationship one with another, as a difference which makes a distinction between one set of gems makes no distinction at all between another set.

"For instance, a diamond which is a crystallized carbon is always called a diamond, without regard to its color, and there are red, yellow, green, blue, and black diamonds, besides the white stones so familiar to everyone.

"Yet the gems composed of crystallized alumina receive a different name for every color; the red variety is called ruby; the blue, sapphire; the yellow, oriental topaz; the green, oriental emerald; the purple, oriental amethyst; and a whole host of delicate shades of every color are known as fancy sapphires.

"The asteria or star-stone is still another variety of this crystallized corundum which occurs in many different shades of color, and displays a shimmering, glittering, six-pointed star, diverging from the center to the edge of the gem, presenting an appearance quite unlike any other precious stone.

"The spinel is a beautiful gem which occurs in almost every color in many different shades, and is known as blue, green, purple, or red spinel respectively. The red and blue varieties of spinel are not infrequently called spinel rubies and spinel sapphires from their resemblance to rubies and sapphires."

From all this it is evident that the nomenclature is indeed a confused jargon, for which the cupidity of dealers is responsible in many instances. The true and the false cat's-eye furnish a case in point. The true cat's-eye is a variety of chrysoberyl, varying in color from a soft yellow to a rich green, and having a glittering streak resembling the iris of the cat. There are, however, two varieties of quartz which have a somewhat similar appearance, but which lack the luster and brilliancy of the true cat's-eye. Commercially, these quartz cat's-eyes are of little value, but by giving them the name of the more valuable gem, dealers are able to get fairly good prices from the unsuspecting, who do not know that there are true and false gems of the same name.

Nothing approaching a scientific nomenclature of gems could be determined until the development of modern chemistry, and an understanding as to the ultimate particles of matter something like a century ago. And it will be recalled that one of the first great steps in the progress of changing the so-called chemistry of previous centuries into an exact science was a systematic change in the nomenclature. This revolutionary change was relatively easy in the case of chemical terms, since most of them were unknown to the generality of people at best, and the scientists were eager to accept the new classification.

The case was very different with the names of gems. The names of a great majority of them were known even to most very ignorant persons. And as is always the case under these circumstances, these popular names cling to them, even though the gem experts have arranged a new nomenclature that approaches at least a scientific classification.

PRACTICAL TESTS

It is apparent from the confusion of names, and confusion of colors of the various gems, where a mistake might cost thousands of dollars, that the gem expert must have at his command some very accurate tests—infallible tests, indeed—to insure against them. The first, most valuable, and absolutely essential one of these, is that of trained observation—a faculty developed only by the handling of countless numbers of cut and uncut gems. In this manner, and in this manner only, can the expert learn to identify most gems without resorting to the tests known to the science of mineralogy. In doubtful cases, however, he fortifies his opinion by elaborate tests which have been developed by modern science. One of these is afforded by the science of crystallography, the knowledge of the various-shaped crystals as formed in the different crystalline substances, a thorough knowledge of this being an essential part of the mental equipment of the expert. The mere matter of color, which is of such importance in determining the market value of a gem, is hardly considered at all in determining its identity, at least until several other tests have been made.

Another important means of identification is the test for hardness. The diamond, of course, heads the list for resisting attrition, while the sphene is at the very bottom, with the other gems ranging in between at definitely determined intervals. The mineralogist Mohs drew up a scale of hardness many years ago, of which the following is a universally accepted modification:—

Diamond	10.0
Sapphire	9.0
Ruby	8.5
Chrysoberyl	8.5
Spinel	8.0
Beryl	8.0
Topaz	8.0
Jargoon	7.5 to 8.0
Emerald	7.5
Tourmaline	7.5
Phenakite	7.5
Alamandine Garnet	7.3
Essonite	7.0
Amethyst	7.0
Kunzite	6.5
Peridot	6.4
Adularia	6.3
Green Garnet	6.0
Opal	6.0
Turquoise	6.0
Sphene	5.0

Mohs' original scale was:—

Diamond	10
Sapphire	9
Topaz	8
Rock Crystal	7
Felspar	6
Apatite	5
Fluorspar	4
Calcite	3
Rock Salt	2
Talc	1

The test for hardness is made by endeavoring to scratch the doubtful gem with each substance of the scale, until one is found that will neither scratch nor be scratched by it. The stone will then be proved to be of the same hardness as the test-stone, and a definite step in the identification is accomplished.

In practice it suffices to use the four hardest in the original Mohs' scale. Bits of these stones are mounted in the end of metal pencil-like holders which are convenient for handling.

Testing a cut gem is a rather delicate operation, as a scratch upon one of the facets might damage it materially. It is customary, therefore, to scratch the test-stone only upon the edge or girdle of the gem. The skilled lapidary can tell by the slightest touch the effect of his test-stone, so that there is little danger of injury.

Determining the specific gravity, or relative weight of a stone, compared with an equal bulk of water, is one of the most important steps in the process of identification. There are several kinds of apparatus for making these tests, but perhaps the simplest and best for ordinary use is a series of solutions of known specific gravity. The stone to be tested is placed in these successively, passing from one end of the scale toward the other until a solution is reached in which it just floats. By having solutions that are carefully made, and a sufficient number so that minute variations can be detected, the exact specific gravity of any gem may be determined in this manner.

Three solutions are in general use for testing all stones but those of the greatest density. Methylene iodide, having a specific gravity at ordinary temperatures of 3.32, but which can be raised to 3.6 by saturating with iodine, or lowered by the addition of benzine or toluene, is an opaque liquid, having a disagreeable odor; a solution having a gravity of 3.28 can be made of cadmium borotungstate, and reduced by the addition of water to any desired lower density; and a liquid known as Sonstadt's solution, which can be made up in solutions of varying density, is an aqueous solution of potassium iodide and mercuric iodide, and is a deadly corrosive poison.

Any of these solutions will do for testing the lighter gems; and even the diamond may be tested with the methylene iodide saturated with iodine or iodoform. But for the heavier stones a colorless compound of the double nitrate of silver and thallium, a substance discovered by the Dutch mineralogist Retgers, which melts at a fairly low temperature, having a specific gravity of 5., and which may be reduced to any desired density by the addition of warm water, is used. As no gem has a density as high as 5., Retger's compound may be used for determining the specific gravity of those stones that are too heavy for testing in the other solutions.

The following list gives the specific gravity of some of the principal gem stones:—

Jargoon	4·7	Chrysolite	3·3 to 3·5
Garnet	4·2	Peridot	3·3 to 3·5
Ruby	3·9 to 4·2	Kunzite	3·2
Asteria	3·9 to 4·2	Tourmaline	2·9 to 3·3
Sapphire	3·9 to 4·2	Phenakite	2·9
Diamond	3·52	Turquoise	2.6 to 2.8
Chrysoberyl	3·5 to 3·8	Emerald	2.6 to 2.7
Alexandrite	3·5 to 3·8	Amethyst	2.5 to 2.8
Cat's-eye	3·5 to 3·8	Moonstone	2·39
Spinel	3·5 to 3·6	Opal	2·21
Topaz	3·4 to 3·6		

The action of light upon precious stones, the optical properties known as refraction, dispersion, polarization, and pleochroism, furnish means of identification that are invaluable. The degree of refraction of a ray of light upon entering a precious stone is characteristic of that particular stone. As a rule this refraction cannot be determined in the rough stone, on account of the unevenness of the surfaces. To cut the gem into a prism for the purpose of examination is of course out of the question. But the same thing is accomplished by selecting two facets of the cut stone having the proper angle for the examination, and then painting over the other surfaces of the gem. By means of the goniometer the refraction and double refraction even of stones of greatest refractive power may then be determined accurately.

A little instrument called the dichroscope, so small that it may be carried in the vest pocket, is useful for determining the pleochroism of gem stones. Pleochroism is the property of doubly-refractive colored gems showing two different colors, or shades, when viewed at different angles. The instrument consists of a metal cylinder "containing a cleavage rhombohedron of Iceland spar, and possesses an eyepiece containing a lens at one end, and a small square aperture at the other. The eyepiece is held to the eye, and the gem to be examined is placed between the other end of the cylinder and the light. Two images of the square opening at the other end of the dichroscope may then be seen, and they will appear either of different colors or of absolutely the same color, according to the nature of the gem stone under examination."

If the two images are of exactly the same color, no matter in what direction the gem is viewed, the stone is singly refractive. If the two colors are different, it is doubly refractive. The determination of this fact is of great importance in identifying a gem.

THE CUTTING OF PRECIOUS STONES

Scientific gem-cutting—the knowledge of how to grind the facets so as to bring out the greatest amount of brilliancy—is a comparatively recent art. Gem stones, as we know, have been used for ornaments, amulets, or in connection with religious rites, since the beginning of history; but in ancient times they were worn either in the natural state, or cut in a crude manner without regard to the arrangement of the refracting surfaces. During the latter part of the fifteenth century, however, some time between the years 1460 and 1480, a gem-cutter of Bruges named Van Berquen discovered that by a certain arrangement of the facets on a diamond the reflection and dispersion of light were greatly increased. The fame of this gem-cutter spread quickly, and many valuable gems found their way into his establishment to be cut. Bruges became the center of the industry and for a time had the monopoly of the industry; but after the death of Van Berquen the craftsmen of the guild scattered to other cities, so that Amsterdam, Antwerp, and Paris divided the trade. Amsterdam and Antwerp still monopolize most of the fine work, although France, England, and even the United States in recent years, have had large gem-cutting establishments. The same methods are employed in all these places, and, curiously enough, the implements and methods used by the diamond-cutters to-day are practically identical with those employed more than a century ago.

It requires something more than the mere mechanical skill of being able to cut a stone into mathematically accurate surfaces to be a successful gem-cutter. Indeed, this particular mechanical part of the art, although essential, is by no means the most important. Every gem is an individual study to the lapidary, a problem of how to produce the maximum brilliancy with the minimum loss of weight. The tone or color, the shape, quality, diaphaneity, the presence of flaws—all have to be taken into account, the complicated mental equipment of the expert gem-cutter contrasting sharply with the simple mechanical equipment needed for the actual process of cutting.

Diamond-cutting, which differs from the cutting of all other gems, is described by the master-craftsman, Leopold Claremont, as follows:—

"The process consists of three different operations: 'bruting,' 'polishing,' and 'cleaving.'

"The bruting of diamonds consists in rubbing two diamonds together in such a way that, by continual friction, each can be made to assume the desired shape. Each diamond is cemented upon the end of a stick or holder about a foot long, and the operator firmly holds one end of each stick in either hand. The stones are then rubbed or pressed one against another over a wooden trough containing a very fine metal sieve, into which fall the particles of diamond dust rubbed from the stones. In order to obtain a sufficient leverage the holders which support the diamonds are held against little metal projections on either side of the trough.

"The dust which falls through the metal sieve is carefully preserved and used later on for polishing purposes. The dust is known as 'diamond powder,' and has exactly the same appearance as slate-pencil dust. Thus, upon the principle of 'diamond cuts diamond,' the stones are roughly fashioned by the bruter into whatever symmetrical form he has designed them to be when finished.

"Another method of obtaining the same result is to rotate one of the diamonds in a lathe and literally to turn it into the desired shape by means of the other stone held against it.

"The small polished flats, known as facets, with which the surface of a diamond is covered, are added subsequently, thus forming another part of the process.

"When the bruter has completed his part of the work, the diamonds are handed to an attendant, who is seated at a bench in front of two flaring Argand burners. Small brass basins, known as 'dops,' which vary in size from one to three inches in diameter, are placed in the flames, and each dop is filled with a mixture of tin and lead in the proportion of one part of tin to two of lead. When this metal has assumed a semi-molten state, it is fashioned into the shape of a cone by means of a large pair of soft-iron tongs, upon the apex of which cone one of the bruted diamonds is carefully embedded.

"After the diamond has been carefully adjusted, the dop containing the cone of hot metal surmounted by the diamond is plunged into cold water; the stone is thus firmly fixed, the dop forming a kind of holder for it.

"The stone is now ready to be handed to the polisher, but it is necessary for it to be returned from time to time to be unsoldered and readjusted in order that a different part of the stone may be brought into prominence, as it is only possible to work upon that part which projects from the metal. This operation is repeated continually until the process of polishing is completed. The operation of embedding diamonds in the metal, as I have described it, is known as 'soldering.'

"An ingenious contrivance for obviating the necessity of using solder consists of a copper holder into which the stone is firmly fixed by means of a forked clamp, which is pressed against the stone and locked in position with a key. The placing of the diamond in this holder requires, if possible, more skill than is necessary to fix the stone in the cone of solder, for it is equally imperative that it should be adjusted at the correct angle.

"The polishing of diamonds is a laborious task, requiring the greatest accuracy. The craftsmen are seated, generally with their backs to the light, in front of revolving wheels, which are made of very porous cast iron. The wheels turn in a horizontal position at about twenty-five hundred revolutions a minute. The technical name for a diamond-polishing wheel is 'skeif.' The dops containing the diamonds are held by means of iron clamps against the surface of the skeif, and kept in position by heavy weights. Four of these clamps are manipulated by each operator at the same time, and he is able to examine first one diamond and then another, occasionally plunging each into cold water to prevent the heat generated by the friction unsoldering the stone, which would occasion considerable damage to the gem and loss of valuable time and labor.

"The surface of the skeif derives its erosive property from the continual application of diamond dust mixed with olive oil, and to the dust which comes off the stones undergoing the process. The facets are polished on to the diamond by means of pressure against this erosive surface, while it revolves at a high speed."

It is usual to cut the diamond into one of three forms, the "brilliant," "rose," or "briolette." The brilliant form is the one into which most valuable gems are cut. The front of a brilliant has an octagonal surface in the center, known as the "table," which is surrounded by thirty-two facets extending to the edge of the stone. The back is pyramidal, having twenty-four facets, reaching from the edge, or "girdle" of the stone to the apex of the pyramid, on which a small facet, the "culet," is cut, parallel with the table.

The "brilliant" is well named, for the maximum brilliancy is developed by this form of cutting. If the cutting is perfect, every ray of light entering the upper surface of the gem is refracted within the stone and out again from the same surface.

The "rose" cutting is only used for small, thin stones that cannot be made into brilliants. The back of the rose-cut gem is perfectly flat, while the front is cut into triangular facets of equal size.

The "briolette" is the cutting commonly used for pendants. Diamonds so cut are pear-shaped, covered with triangular facets, and frequently drilled through the pointed end.

It often happens that projecting parts have to be removed from rough diamonds before they can be cut into the desired form. This is done by a process of "cleaving," which, as the name implies, is splitting off a portion in the direction of the natural cleavage. The natural tendency of the diamond is to divide along certain planes parallel to the face of the octahedron. To take advantage of this, the craftsman cements the diamond to the end of a stick so that the plane of cleavage to be used lies in the same direction as the length of the stick. The end of the stick is then rested against the top of the work-bench and a steel blade held against the diamond at the proper point. A sharp blow upon the blade will then split the stone easily and accurately. To do this successfully requires not only great skill, but an accurate knowledge of crystallography.

When it is undesirable or is impracticable to cleave a diamond, the gem is sometimes divided by sawing with a small, thin metal disk, the edge of which is prepared with diamond powder. This sawing is a tedious operation, sometimes requiring several weeks, and most experts maintain that some of the luster and brilliancy of a gem are sacrificed in the process. As there seems to be no reasonable explanation of this loss of brilliancy, however, it is possible that it is largely imaginary.

In diamond-cutting, in addition to the necessary skill, a great amount of force is used; whereas, in cutting such stones as sapphires, emeralds, rubies, etc. —the "oriental gems," as they are called—a delicacy of touch must be acquired which is quite as essential to good workmanship as a knowledge of the way the surfaces should be cut. The gem to be cut is cemented to the end of a piece of hard wood, or ivory, about the size of a lead pencil, so as to be conveniently held in the hand. Using this as a handle, the gem-cutter holds the stone at any desired angle against a horizontal revolving metal disk covered with some erosive material such as diamond dust, emery, or carborundum, whichever is best suited to the nature of the stone to be cut. The gem is first fashioned roughly into the shape it is ultimately to assume, and all faulty parts are removed. The facets are then cut, and the stone is ready for polishing. The majority of transparent stones are cut in the form of "brilliants," although the emerald is the exception, being cut square or oblong in the form known as the "step-cut." Such stones as the opal, turquoise, moonstone, cat's-eye, and star-stone are not cut with angular facets, but with curved convex surfaces, or "en cabochon," as it is called.

Just as in the case of the diamond, the cutting process is followed by that of polishing the gem. The polishing-wheel may be made of either iron, brass, gunmetal, copper, lead, tin, pewter, felt, or one of half a dozen other materials that have been found to be the best for polishing the particular stone in hand. It is smeared with some such material as rotten-stone.

Cutting reduces the weight of the rough stone very materially, as is shown by the following table giving the loss in weight of some of the famous diamonds:—

Name	Original Weight Carats	Weight after Cutting Carats
Excelsior	970	239
Great Mogul	560	279
Orloff	400	193
Koh-i-noor	393	186
Star of the South	250	125

The original weight of some of these gems can only be estimated. The carat is the unit of weight for precious stones, and is about 3.2 grains.

DIAMONDS IN THE ROUGH

Diamonds crystallize in the cubic system and generally occur in the octahedron, or rhombic dodecahedron form. Sometimes they have the appearance of being spherical, and frequently they are twinned.

At the present time the South African mines are the world's chief source of diamonds. The diamond-bearing material of these mines is found in fissures in the rocks supposed to be of volcanic origin, which have been filled in with the material containing the diamonds at a later period. This diamond-bearing earth is called "Kimberlite," and occurs in three distinct layers with three degrees of hardness. The lowest of these is known as "hard bank," which, as its name indicates, is very hard. Above the "hard bank" is the softer "blue ground," so named from its bluish color. And above this the "yellow ground," greasy to the touch, soft, friable, and yellowish in color. Yellow ground and blue ground are supposed to be decomposed stages of the hard bank, the different colors being due to the presence of different iron oxides.

Some of these diamond-bearing veins can be worked from the surface in the early stages of mining, but if the work is to be carried on extensively it is necessary to sink shafts and tunnel just as in other subterranean mining. The yellow ground, being soft and friable, may frequently be worked as soon as it is brought to the surface; and it is possible to work even the hardest material by crushing. It is more economical and satisfactory, however, to spread this hard material out in thin layers and allow it to be acted upon by the elements. At Kimberley there are great fields, or "floors," covering many square miles which have been specially prepared for this purpose. The blue ground is spread over this to a depth of two and a half feet, and allowed to disintegrate, the process taking from a few weeks to two years. Even then it is sometimes necessary to reduce the harder masses in the crushing-mill.

From the floors the material goes to the washing-plant, where the heavier materials are separated from the lighter ones by complicated washing and agitating machinery. This heavier material containing the diamonds is passed on to machines known as pulsators, which concentrate and drain the diamond-bearing gravel, from which the gems are either picked out by hand, or removed by a machine called the "greaser." This machine consists of a shaking-table containing a series of steps, each step covered with a layer of grease. As the gravel containing the diamonds is washed over these, the gems adhere to the grease, while the pieces of gravel pass on. To insure against possible oversight the gravel is often picked over once or twice by hand before going to the greaser. The diamonds are then cleaned by a mixture of sulphuric and nitric acid, sorted, and are ready for the market.

While the great mines, such as have just been described, produce ninety-nine per cent. of the yearly diamond output, those that make up the remaining one per cent. are still collected by the primitive method of washing by hand. The rivers coming from the regions of diamond-bearing earths bring down the detritus from the rocks; and among the gravel in their beds fine diamonds are found periodically by the solitary washers who are always at work somewhere along the streams. These streams are outside the lands, and beyond the control, of the Kimberley and De Beers mine owners, and the diamonds found in them, curiously enough, are superior to those taken from the mines.

The discovery of diamonds in South Africa was made seventeen years after the finding of gold in California; and the story of this discovery, with the resulting extensive change of the political map of the world, makes a thrilling chapter in world history. It begins with the children of a certain Dutch farmer named Jacobs, who lived near Hopetown between Cape Town and

Kimberley. These children, playing in the shallow water of a little tributary of the Orange River, gathered handfuls of pretty stones from time to time, which they took to their home as playthings. One of these stones, of peculiar shape and very bright, attracted the notice of their mother. She knew nothing of precious stones, but surmised that this one might have some market value. She made no attempt to dispose of the stone, however, and had all but forgotten it, until some time later during the course of the conversation with an old friend of the family, Schalk Van Niekirk, who was paying a visit. Then it developed that the children, tiring of their plaything, had lost it somewhere about the yard; and it was not until after a long and diligent search that it was finally found in the garden.

Little did the Jacobses suspect that their successful search would change the history and map of South Africa.

They did believe, however, that the stone had some value, and so did their visitor, who offered to buy it. The Jacobses would not hear of this—this probable imposition on an old friend—but they gave Van Niekirk the stone, telling him jokingly to "sell it and make his fortune." In the end he carried out their instructions to the letter.

The story of the peregrinations of the little stone for the next few months reads like a fairy tale. Van Niekirk turned the stone over to his friend, O'Reilly, who carried it with him to Hopetown, where everyone laughed at him for supposing that it was valuable. But even the most skeptical were obliged to admit that it was beautiful, and a most remarkable stone in many ways. For example, it would cut glass as no other stone in the country would do; and the enthusiastic O'Reilly cut his name in more than one windowpane in Hopetown for the amusement of groups of spectators. Those who had any knowledge of minerals supposed that the little crystal was simply an unusually pretty, but valueless, rock-crystal.

Failing to get any definite information in Hopetown about the gem, O'Reilly sent it in an ordinary gummed envelope through the mail to a Dr. Atherstone, a mineralogist of Grahamstown. Dr. Atherstone at once suspected its identity, but being in doubt, he sent for his friend Bishop Ricard, who knew something about gems. After making exhaustive tests the two men reached the conclusion that the stone must be a diamond, although such gems had never been found in South Africa. Such a momentous discovery needed most authoritative confirmation, and at the suggestion of the Colonial Secretary, the Hon. R. Southey, the stone was sent to the Paris Exhibition of 1867, then just opening. Here it was examined and admired by savants from all parts of the world, who without exception pronounced it a diamond. It was finally sold to Sir Philip Woodhouse, at that time Governor of Cape Colony, for a sum amounting to about twenty-five hundred dollars. The gem weighed a little more than twenty-one carats.

Whether the little finders of this first South African diamond found more of its brothers and sisters and sold them for fabulous sums, and became wealthy as princes, as they certainly would have done in any good fairy tale, does not appear. But it is certain that their friend Van Niekirk found other gems, and bought still others from the ignorant natives. One of these he sold in Hopetown for over fifty thousand dollars; and it would have brought him much more had he sent it to London. This stone is now the famous "Star of South Africa."

OTHER SOURCES OF DIAMONDS; PRACTICAL USES

Until the opening of the South African diamond mines, India and Brazil were the chief source of these gems, with Borneo, British Guiana, and Australia furnishing the remainder. India had supplied the world for centuries, most of the famous diamonds coming from that country. On account of certain restrictive laws, however, the Indian mines have never been worked on such extensive scale as the South African.

Diamonds were discovered in Brazil in 1728 and have been mined there ever since. The stones found are of fine quality, and, like the Indian gems, are considered more valuable than those coming from South Africa.

The diamonds of Borneo have great depth of color, and bring good prices; but the industry is not developed to any such extent as in South Africa. The Australian gems are very hard and brilliant, but of such small size that they can only be used for certain pieces of jewelry. The stones from British Guiana are of good size and quality, but as the mining industry is only recently developed there this country does not compete at all with the older sources of supply.

Certain straight-laced, Puritanically minded persons who are inclined to condemn the diamond as a useless bauble, must find some satisfaction in the knowledge that this gem is a most useful—indeed, an indispensable—substance for certain mechanical purposes. The most important of these is in forming the cutting surface of the diamond drill for use in all kinds of mining operations. The diamond drill is, to the miner, what the compass is to the mariner. For making it the imperfectly crystallized or otherwise defective stones, unsuitable for cutting into gems, and which are known as "boart," are used. Such pieces, when set in the end of a steel tube which is rotated by machinery, make a drill that will cut its way through the hardest rock. Not only cut through, but bring to the surface pieces of the rock through which the drill is passing, so that the miner, working many feet above, can keep himself informed as to the nature of the successive strata beneath him almost as well as if the intervening layers were removed. He can locate an ore-bearing stratum, or vein of coal, find its exact thickness, and determine its quality, without the laborious, expensive, and frequently disappointing process of sinking a shaft. Thus the ill-favored and deformed relative of the useless bauble of fashion plays an important part in a most important industry, and acts for the community at large, and in this way helps to remove the stigma from the name of its more beautiful and favored sisters.

THE RUBY AND ITS ALLIES

The ruby has been called "the most coveted of Nature's treasures," since it represents a greater amount of wealth in a smaller bulk than any other precious stone. It is one of the varieties of the mineral corundum, which ranks very high in the scale of hardness, and is a most useful substance for abrasive purposes. In the opaque forms corundum enters largely into the composition of emery, while its translucent forms are gems having the widest range of colors and shades. Thus the ruby is red corundum; sapphire is blue corundum; "oriental emerald" is green corundum; "oriental topaz" yellow corundum; and "oriental amethyst" purple corundum. To the chemist these stones are identical, differing only in an infinitesimal amount of coloring matter; but to the prospector, miner, and dealer, this minute difference in coloring matter means the difference between day-wages and boundless riches.

While ordinary varieties of corundum occur plentifully all over the world, the variety which we know as the ruby is extremely rare. Rubies of inferior quality, and in small quantities, have been found in several places, but the three great sources of the gems to-day are Burma, Siam, and Ceylon. Burmese rubies are considered the most valuable, since a greater number of them have the "pigeon-blood" color—the color of the blood of a freshly killed pigeon—which is most highly prized by the connoisseur.

For many centuries the location of the Burmese ruby-mines was a secret closely guarded by the monarchs of that country, who held them as royal possessions. It is said that from time to time adventurers had attempted to locate them, but none of these ever returned to tell of success or failure; and it was not until Great Britain annexed the country that the exact location of these mines became known to the outside world. Needless to say, shortly after this had been accomplished, a company was formed to work the mines and introduce modern mining methods.

These methods are most simple, and differ from the older ones very largely in the matter of replacing hand-labor with machinery. The ruby-bearing material is mined, brought to the surface, and washed in machines very similar to those used in diamond washing.

The Siamese rubies rank next to the Burmese, but are distinctly less valuable, and usually darker in color. Those of Ceylon, on the other hand, are much lighter in color, limpid and brilliant, and even less valuable than the Siamese. France alone seems to appreciate their beauty and artistic qualities, and most of them are marketed in that country.

The sapphire, the corundum gem stone next in importance to the ruby, is of a peculiar interest to Americans, since it is the most important precious stone produced in the United States. Australia, Kashmir, Siam, Burma, and Ceylon also continue to furnish sapphires in considerable quantities, but the quantity and quality of the Montana gems have recently rather overshadowed those from the other sources of supply. The coveted "cornflower blue" sapphires, which were formerly found only in Burma, Ceylon, and Siam, are now found in the Montana mines; and the uniformity of color and peculiar brilliancy of the American sapphires have made them favorites with many European dealers.

For many years sapphires of pale tints of yellow, pink, and bluish-green have been found in the Montana gold-mining region, but these stones have very little commercial value. In 1895, however, blue sapphires of fine quality were discovered, quite by accident. A gold-mining company in the Judith River district, after installing an expensive plant, found that the gravel contained such a low percentage of gold that it would not pay the expense of mining and working. But certain blue stones were found in the sluice-boxes, and were soon identified as sapphires. The gems occur in a dike of trap-rock which cuts through the limestone in this region. This dike is several miles long, showing as a depression covered with vegetation running through the limestone ledges. Pocket-gophers find it an excellent place for their subterranean operations, and in the mounds thrown up by these little miners many valuable gems have been found. The animals follow the course of the trap-rock, since the surrounding rocks are too hard for burrowing, so that the mounds they throw up serve as a guide to the prospectors in locating the sapphire-bearing vein.

The material in which these sapphires are found varies in hardness in different localities and positions. A hard clay, not unlike the diamond-bearing clay of the South African mines, furnishes a large proportion of the gems. It is worked by cutting and disintegrating by powerful streams of water, reducing it to a loose mud, which is then washed through a long series of wooden boxes. Across the bottom of these boxes, strips of iron two and a half inches high are placed and against these the sapphires find lodgment, while the lighter particles of gravel are washed away.

Besides the blue sapphire, which is of course the most highly prized gem of the sapphire group, there are the yellow sapphire, known as the "oriental topaz," the purple sapphire, known as the "oriental amethyst," the green sapphire, known as the "oriental emerald," and the "fancy sapphires" of almost all shades and tints. None of these stones has any very great commercial value as compared with the corundum in the form of rubies or blue sapphires. Yet many of them are beautiful and brilliant stones. Unfortunately they resemble other cheaper forms of stones, and this, with the caprices of fashion, seems to keep them from merited popularity. Many of these gems are found in Montana associated with the more valuable blue sapphires; and Burma, Siam, and the other sapphire-producing countries furnish great quantities of them for the cheaper grades of jewelry.

There is still another form of corundum gem, the asteria, or star-stone, which is one of the most interesting of stones. It is a semi-transparent stone, which when cut with a convex rounded surface which lies at an exactly right angle to the principal axis of the crystal, shows a six-pointed, shimmering star of great brilliancy. As the other portions of the stone remain lusterless and dull the contrast is very marked and the effect very beautiful.

These star-stones vary in color, although the rays from the star are always the same. When red they are called "star rubies," and when blue, "star-sapphires." Very few, if any, good specimens of these stones are found in the American sapphire regions, Ceylon, Burma, and Kashmir supplying the market.

The explanation of the appearance of the star in the star-stone lies, of course, in the structure of the crystal. When cut at right angles to the principal axis, peculiar striations and markings parallel to the face of the prism are found. These consist of innumerable minute cavities, forming three lines which cross one another in the center at an angle of sixty degrees, producing the six-pointed star.

Only second in importance to the corundum stones —if, indeed, they are not quite as important as gems— are the beryls, which include the emerald and the aquamarine. Chemically all these stones are practically identical; but here, as in the case of the corundum gems, the infinitesimal difference in the coloring matter makes such an enormous difference in the commercial value of the individual stones. The combination of elements that enter into the formation of beryl is:—

Silica	68.0
Alumina	18.3
Glucina	12.2
Magnesia	0.8
Soda	0.7

The color of the emerald is due to the presence of a minute quantity of oxide of chromium. Fine emeralds are frequently alluded to as "Spanish emeralds," giving the natural impression that Spain was the source of these very fine gems. In point of fact there are no emerald mines in the Spanish peninsula, and there never have been. But there were great quantities of emeralds kept as ornamental trinkets by the natives of Peru at the time of the Spanish conquest, and like almost everything else of value there, they soon found their way into the hands of the Spanish nobility. For many years, therefore, the finest specimens of emeralds were in Spain, and hence the term "Spanish emerald" was a presumptive guarantee of fine quality.

Emeralds have always been found in Africa, and there were Egyptian mines many centuries before the Christian era. Asia, North America, and Australia also produce the gems in small quantities. But the principal source is still the South American continent, Colombia and Peru being the centers of supply. The mines of Muzo and Coscuez in Colombia, discovered about 1550, still supply the world with the greatest quantity, and finest quality, of emeralds. They are found in limestone and slate, occurring in lodes or as isolated crystals.

A somewhat less important group of gems, whose range of colors equals the corundum gems, are those of the mineral spinel. They are not as brilliant stones as the corundum or beryl group, but the finest specimens are sometimes only slightly inferior. In proof of this is the fact that the "Black Prince's ruby" in the crown jewels of Great Britain, which was until recently supposed to be a ruby, is said to be a red spinel.

The finest spinels are found in Brazil, India, and Ceylon. Those somewhat inferior in quality are mined in Burma, Siam, and Afghanistan from limestone, gneiss, or volcanic rocks. A certain number have been found in the United States, mostly in New York and New Jersey.

Reference was made in the early pages of this chapter to the chrysoberyl, one variety of which is that remarkable gem, the cat's-eye. Quite as extraordinary as this kind of chrysoberyl is another variety known as alexandrite. This gem, so called because of its discovery in the Ural Mountains on the birthday of Czar Alexander II, has the remarkable quality of changing color from a rich green by daylight to a raspberry red by artificial light. Only the better quality of gems give this distinct change of color, and as these are rare, and difficult to obtain, this gem has never had the vogue that it probably would otherwise have attained.

Quite as remarkable, but much more common, are the group of gem stones which have the property of dichroism—appearing in different colors when viewed from different directions. The tourmalines, having a wide range of colors and shades, are the best examples of this. Thus a crystal of tourmaline when viewed along the length of the crystal may be almost black, while the same crystal if viewed across may be a bright green, or some other color quite as striking. The finest tourmalines come from Brazil, but more or less valuable gems are found on every continent.

We have not space here for consideration individually of each of the principal precious stones, but in another place will be found tables giving the composition, location, and characteristics, etc., of the more important. The subject of artificial gems and imitation gems will be considered in a moment. But before beginning this subject of growing importance, a word should be said as to the methods employed by unscrupulous gem dealers of using thin layers of true gem stones, in connection with colored glass, as a veneer for making what appear to be very good gems. These are made in two forms, and are known to the trade as "doublets" and "triplets," respectively. Doublets are made by cementing a thin piece of some gem stone over a paste, or glass, backing of the same color, so that the top of the stone above the setting responds to the tests of the real gem. By testing the under side of the stone the fraud is revealed. Triplets are made by placing thin layers of a gem stone both front and back of the paste, so that the glass is sandwiched in between, and can only be detected at the edges, which are usually carefully covered by the setting.

It is possible to alter the color of certain stones by the careful application of heat, the process being known technically as "pinking," or "burning." This is a perfectly legitimate process, however, and enables the jeweler to convert certain topazes, for example, into gems of coveted pink color. Pink topazes occur very rarely in Nature; but as they are seen very frequently on the market it may be taken for granted that most of those offered in the shops have been "pinked." By the same process the purple amethyst can be changed to a mahogany-brown stone of great beauty; and brown zircons and brown quartz can be made colorless. There is great danger of ruining the gem during the transformation process, which consists in burying it in sand and heating to the desired temperature, afterward allowing it to cool very gradually.

ARTIFICIAL GEMS

The production of artificial diamonds has long been the dream of the experimenter. The conditions under which diamonds are produced in nature are pretty well understood; and on a small scale they have for some time been duplicated in the laboratory, and even—though here quite unwittingly—in the workshop. Nothing more is necessary than to reduce carbon—a bit of coal or graphite or lampblack—to a liquid condition, and maintain it under great pressure until it cools, when crystals of carbon will separate from the liquid just as crystals of quartz or sugar or salt separate from their respective solutions under like conditions; and these crystals of carbon constitute true diamonds. But the difficulty lies in the extreme reluctance with which carbon assumes the liquid state. Unlike most other substances, it volatilizes directly from the solid state under ordinary conditions of pressure—the temperature at which the change occurs being about 3600 degrees Fahrenheit. Under pressure, to be sure, it will liquefy; but the pressure required, according to Professor Dewar's experiments, is about fifteen tons to the square inch. In the depths of the earth, such a weight may be applied by the weight of geological strata; but how may it be obtained in the laboratory?

A most ingenious answer to this question was found by the late Prof. Moissan of Paris. It is based on the well-known fact that the metal iron has the peculiar property, which it shares with a few other substances, including water, of expanding instead of contracting as it passes from the liquid to the solid state; combined with the further fact that liquid iron absorbs or dissolves carbon, much as water does sugar, in increased quantity with increased temperature. Moissan filled an iron receptacle with pure iron and pure carbon obtained by calcining sugar; closed it tightly and heated it rapidly to the highest attainable temperature in an electric furnace—bringing it to a degree of heat at which the lime furnace begins to melt, and the iron to volatilize in clouds. The dazzling fiery receptacle, before it has had time to melt, is lifted out and plunged instantly into cold water until its outer surface is cooled and hardened, thus forming a shell of iron that holds the interior contents in an inflexible grip. As this molten interior matter cools, the carbon separates from the iron solvent in liquid drops; and under the almost unimaginable stress of expansion of the solidifying iron, these liquid drops become solid crystals—of diamond.

By a long slow process the iron ingot and the various impurities are dissolved and fused away, until nothing remains but the pure diamond crystals; and these are but fragments of the crystals originally obtained, which, having been formed in a condition of great internal stress, break on the smallest provocation—a phenomenon also observed sometimes in the case of the natural diamond. The mere liberation from the intense pressure under which the gems are formed appears to be enough to cause them to fly into fragments. The fragments themselves, however, have all the characteristic stability and hardness of ordinary diamonds.

The conditions which may thus be established in the laboratory are duplicated to some extent in the commercial manufacture of certain kinds of steel, which are cooled from the molten state under intense hydraulic pressure; and steel so made may actually contain microscopic diamonds, as Professor Rosel, of the University of Bern, has demonstrated. It has even been suggested that the hardness of steel may be due, in part at least, to the presence of diamond particles everywhere in its substance. Ordinarily these diamond crystals, where they exist in steel, are almost infinitesimal in size; but in one case, in a block of steel and slag from a furnace in Luxembourg, a clear crystalline diamond was found measuring about one-fiftieth of an inch across—this being the largest artificial diamond yet recorded.

The theory of diamond-making being so well understood, it may hardly be doubted that the manufacture of these gems will some day be placed on a commercial basis—the manufacture, that is to say, of veritable diamonds, indistinguishable by any tests whatsoever from the products of the mines; this being true of the minute diamonds produced in Professor Moissan's furnace and in the steel ingots. It would be futile to predict how soon diamonds of marketable size may be produced; but in the mean time the similar problem of manufacturing relatively large gems of other kinds—rubies, sapphires, oriental emeralds, the oriental amethyst, and the oriental topaz—has yielded its full secrets to science. Artificial gems of these various sorts are already on the market, in actual competition with the natural gems, the properties of which they duplicate rather than imitate.

Just as the brilliant diamond is only a particular state of so familiar and inexpensive a substance as carbon, so these sister gems—some of them even exceeding the diamond in value weight for weight—have for their basis, as already noted, the metal aluminum, which, as is well known, is a most familiar constituent of the soil everywhere. They are, in short, merely crystalline forms of the clayey earth, alumina—a compound of aluminum and oxygen. If no coloring matter is present, this crystal is called a white sapphire. Usually, however, a trace of some chromium or cobalt salt is present, and then the gem becomes a true sapphire, a ruby, an amethyst, an oriental emerald, or a topaz, according to color. The presence of a small percentage of magnesium and of sodium may greatly mar the hardness and hence the real value of the stone, without greatly altering its appearance to casual inspection. A large proportion of the alleged rubies on the market, for example, have this defect, and would not be classed by legitimate dealers as true rubies, but as "spinel" or "balas" rubies. The ordinary amethyst of the market bears even less resemblance to the true oriental amethyst, being merely a quartz crystal and of far too little value to merit attention from the manufacturer of artificial gems.

Gems of the true sapphire order are manufactured by bringing alumina to a liquid state, by the agency of extreme heat; the gems crystallize from the solution on cooling. Fortunately it is not necessary, as in the case of the diamond, to have the operation performed under pressure; hence the relative facility with which these gems may be produced. A practical difficulty is found, however, in the fact that the crystals tend to take the form of thin plates, unsuited to the purpose of the gem-cutter. This is the chief reason why artificial rubies and emeralds have not long been familiar in commerce, for it is almost seventy years since the first true rubies were made in the laboratory. The earliest successful experiments in this direction were made by Gaudin in 1837, who produced true rubies of microscopic size. Ten years later Ebelmen produced the white sapphire and the ruby-like spinel; but it was not until 1877 that MM. Fremy and Feil succeeded in making crystals of a size from which gems could be cut; and still another quarter of a century elapsed before a method of manufacture was devised that could put the enterprise upon a commercial basis.

The original experimenters, and numerous succeeding ones, adopted the method of fusing alumina in the presence of some substance, such as borax or barium fluoride, that would act as a solvent. As the solvent evaporated, the alumina crystals were deposited, their color being predetermined partly by the quantity of chromium salts placed in the original mixture, and partly by the degree of heat employed. But the one great difficulty about the shape of the crystals long proved insuperable. It was finally met, however, through the ingenuity of M. Verneuil, a Frenchman already well known for his experiments in this field, who devised a method by which the alumina powder —prepared originally from a solution of common alum—is sifted down a tube through an oxy-hydrogen flame and, thus fused, is deposited drop by drop, or more properly as a spray, on a fixed point below the flame, where it builds up a pear-shaped crystal precisely as stalagmites are built up by dripping water in a cave. Unfortunately the gem thus formed breaks into fragments when touched; but the fragments are still of marketable size; and true rubies and sapphires thus manufactured have now entered the field of commerce.

Rubies and sapphires so formed duplicate absolutely the desirable qualities of the natural gems; and their production must obviously affect the market value of these gems, as well as the mining industry through which they are obtained. The public should be warned, however, against accepting as "true artificial" rubies, emeralds, and sapphires, the numberless glass imitations that will continue to flood the market so long as these jewels retain their popularity.

APPENDIX

REFERENCE LIST AND NOTES

CHAPTER I

AN INDUSTRIAL REVOLUTION

(pp. 31-32.) The quotation is from the "History of Cotton Manufacture," by Edward Baines, Jr., London (not dated). This work gives a valuable account of the spinning- and weaving-industries. The author leans towards the opinion that Arkwright may have gained the idea of his revolutionary spinning-process from the earlier patent of Lewis Paul. He advances testimony of convincing character to show that Paul (possibly in association with his partner, John Wyatt) actually invented a mechanism of similar type to that which afterwards made Arkwright famous. It is not at all in doubt, however, that it was Arkwright and not Paul who was responsible for making the mechanism a commercial success; therefore, according to the usual standards by which such matters are adjudged in the public mind, Arkwright must always be given the honors of the inventor. He seems to have been a man of such ingenuity that almost every mechanism with which he had to deal was improved at his hands.

CHAPTER II

THE MANUFACTURE OF TEXTILES

(pp. 40-41.) The origin of weaving. The quotation is from "Cotton Weaving: Its Development, Principles, and Practice," London, 1895, pp. 16, 17.

(pp. 56–57.) Knitting-Machine. The description is taken from the admirable summary of the development of textile machinery given in the Catalogue of the Victoria and Albert Museum, London.

CHAPTER III

THE STORY OF COSTUMES

(p. 66.) Fashion *versus* Law. The quotation is from "A History of English Dress," by Georgiana Hill, 2 vols., New York, 1893.

(pp. 67–68.) Philip IV and the ruff. The quotations are from "The Court of Philip IV," by Martin Hume, New York, 1907.

(pp. 74–75.) Relating to hoop skirts. The quotation is from "A History of English Dress," by Georgiana Hill, New York, 1893.

CHAPTER IV

THE SEWING-MACHINE

(p. 88 and pp. 93–94.) The claims of Howe. The quotations are from a work published in New York in 1860, presenting the case argued by George Gifford, Esq., in favor of Elias Howe, Jr., for an extension of his patents for sewing-machines. In the course of the proceedings it was testified that Howe's original machine, operating in 1845, was tested as to speed against the hand-work of five girls, and beat them. Again, that the same machine was operated at the rate of 280 stitches per minute, doing good sewing. Evidence was also adduced to show that sewing by hand would not equal 40 stitches per minute; hence that Howe's machine did work equal to that of seven hand-workers. "It must be borne in mind that this is the work and capability of the machine as Howe originally constructed it, and of the first machine he made. It was, therefore, the work of his invention, unimproved, unaltered, and untouched by others."

(pp. 98–102.) The Development of the Sewing-Machine. The quotation is from the *Twelfth Census Report* of the United States, 1900, published Washington, 1902, vol. X., pp. 415–417.

APPENDIX

CHAPTER V

CLOTHING THE EXTREMITIES

Material for this chapter is largely drawn from the article on *Boots and Shoes*, by Mr. George C. Houghton, and the article on *Leather Gloves and Mittens*, by Mr. Arthur L. Hunt, both in the *Twelfth Census Report* of the United States, Washington, 1903. The quotation beginning at p. 108 is from Mr. Houghton's article, as stated in the text; and the section on the manufacture of gloves is largely based on Mr. Hunt's exposition of the subject.

CHAPTER VI

THE EVOLUTION OF THE DWELLING HOUSE

(pp. 134–136.) Habitations of the Cave Dwellers. The quotation is from "Les premiers Hommes et les Temps Historiques," by the Marquis de Nadaillac. Translated by Nancy Bell, New York, 1906.

CHAPTER VII

THE MODERN SKYSCRAPER

(pp. 179–180.) Statistics as to wind pressure. The quotation is from *The Scientific American*, December 15, 1908, p. 401.

CHAPTER VIII

ARTIFICIAL STONE, OR CONCRETE

(pp. 185–186.) Concrete Blocks. The quotation is from "The Manufacture of Concrete Blocks," by H. H. Rice, New York, 1906.

(pp. 198–199 and 200-201.) Concrete as a Preservative of Iron. The quotation is from "Reinforced Concrete," by Charles F. Marsh and William Dunn, New York 1907, p. 7.

(pp. 209–212.) The Construction of a Concrete Building. The quotation is from *The Scientific American*, Feb. 15, 1908, pp. 109–110.

CHAPTER X

THE PRODUCTS OF CLAY AND FIRE

Much valuable information for this chapter has been obtained from "Notes on the Manufacture of Earthenware," by Ernest Albert Sandeman, London, 1901, and quotations on pp. 239 and 249–251 are from that work.

CHAPTER XI

GLASS AND GLASS-MAKING

(p. 283.) Glass a luxury in the Middle Ages and in the Early Modern Period. The quotation is from "Wonders of Glass-Making in all Ages," by Alexandre Sauzey, New York, 1875.

(pp. 284–285.) The Composition of Glass. The quotation is from "La Manufacture de St. Gobain," by M. A. Cochin.

CHAPTER XII

GEMS, NATURAL AND ARTIFICIAL

(pp. 306–309.) Diamond-Cutting. The quotation is from "The Gem-Cutter's Craft," by Leopold Claremont, London, 1906, pp. 40–46, from which work information of great value has been derived for other portions of this chapter.

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